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OVERALL EFFICIENCY OF AN INTEGRATED ENERGY PRODUCTION MANAGEMENT SYSTEM AND A FIREPLACE INSERT

Prepared by

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October 15, 1984

Prepared for

Montana Department of Natural Resources and Conservation
1520 East 6th Avenue, Helena, Montana 59620
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ABSTRACT

A contract was signed between the Energy Division of the Montana Department of Natural Resources and Conservation and WRENCH & ASSOCIATES January 1, 1984 to determine the overall efficiency of an integrated energy production and management system and a fireplace insert. Both systems are located in the home of Richard G. Wrench, Kalispell, Montana.

The integrated energy production/management system consisted of a Riteway Model 37 wood furnace, an air handling system, air-to-air heat exchanger to recover flue energy and a clock operated night time temperature set back thermostat. The design of the home was conventional 2x4 walls with 3½ inch insulation and 9½inch insulation in the ceiling. A plastic moisture seal was installed around the perimeter.

The inside and outside temperatures were recorded daily for the 1983-84 heating season along with the weight and volume of the wood burned. Based on the daily differential temperatures, a heat loss analysis determined the theoretical energy required to heat the home and 130 gallons of hot water. This was compared to the potential energy contained in the fuel to calculate the overall efficiency of the system. Depending on which energy heat loss model used,the overall efficiency was 73% or 87%.

The fireplace insert was developed by Richard G. Wrench during the 1981-82 time period under a Grant from the Energy Division of DNRC.The unit is a double wall,sealed firebox with a bottom opening for exhaust.The potential heat contained in the fuel was compared to that actually delivered into the room

by a forced air system and radiant heat.The insert fits completely inside the fireplace.A lever, recessed out of sight, opens and closes the top access to the chimney to prevent smoke from entering the room when loading wood. The cast iron doors are removable by lifting off. This allows the insert to be used as a conventional fireplace for aesthetical purposes. The overall efficiency, delivered heat divided by potential heat in the fuel, was in the 85% to 90% region.

Both systems can be replicated for costs comparable to conventional construction and heating components for the energy production management system and for a comparable fireplace insert.The overall efficiency of both systems points out low cost, high efficiency renewable energy systems are practical. With the increased efficiency came a reduction in chemical and particulate pollutants.The home and its energy system were the latest in a series of research, design, construction, testing and monitoring conducted by R & J WRENCH, & ASSOCIATES over the preceeding 15 years. The goal has been to develop the technology to design and build homes that use renewable energy and will cost no more to obtain than conventional homes. The second goal, that of heating the home for less cost than conventional energy costs was demonstrated during this monitoring program. A 3,600 square foot home and 130 gallons of domestic hot water was heated during the 1983-84 season for 5.3 cords of wood for a cost of $265. This technology is applicable to heating other structures.

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EXECUTIVE SUMMARY

Purpose

The fundamental purpose of the funds provided by the Energy Division, DNRC, is to lessen the state's reliance on fossil fuels. The specific purpose of this contract was to determine the overall efficiency of an integrated energy production/management system and a fire place insert developed with Grant funds provided by DNRC during the 1981-82 time period.

Scope

Performance monitoring was conducted on a 3,600 square foot private residence located on a hill looking into Glacier National Park,five miles north of Kalispell, Montana. A renewable energy, wood furnace, heating both the home and 130 gallons of domestic hot water,was monitored to determine the overall efficiency of converting potential energy contained in the wood into delivered energy. A fireplace insert was also tested to determine its overall efficiency and its various modes of operation and limitations. The testing took place during the winter heating season of the 1983-84 time period.

System Description

Integrated Energy Production/Management System

The home is conventional 2x4 wall construction. The outside walls have 3½ inches of fiberglass blanket insulation. The ceiling has 9½ inches of fiberglass insulation. A sheet of plastic is stapled under the sheet rock in the ceiling and on the inside and outside of the perimeter walls.

There are two floors, each with 1,800 square feet, for a total of 3,600 square feet of heated space. No special construction precautions were taken, except to insure the dryness of the exterior walls prior to applying the plastic inside and a 1½ foot overlap of the wall plastic to the ceiling.

The heating system is constructed from standard components. A Riteway, Model 37 wood furnace was selected due to its efficiency and BTUH capacity. A small backup electric furnace provided a blower, air filter and a source of heat to prevent freezing when away on a winter vacation. The following three principals are the key design parameters requisite to efficiency.

(1)Heat is to be produced at the rate the building is losing to the outside on a constant, 24 hour a day basis. This means sizing the furnace for the average January BTUH net building heat loss and operating it in this manner.
(2) Air is to be circulated continuously from the furnace, removing heat as it is being produced, to the floor ducts in each room that are designed to deliver the BTUs being lost by the room, vortexed through the entire room volume to maintain a uniform temperature gradiant, removed from the ceiling before a temperature buildup can occur, passed through an air-to-air heat exchanger to recover flue energy and returned to the furnace to replace the heat just delivered/lost to the outside.
(3) Cost-Effective conservation measures, not expensive super insulation, are to be installed.

Additional features were the use of outside combustion air and a clock operated thermostat for night time temperature setback. The home was pressurized by bleeding in heated external air to reduce cold air infiltration.

Monitoring

Each time wood was loaded, it was weighed and the time, date and weight was recorded. Every four hours the average of several thermometers was taken to record the exact outside air temperature and inside temperature, along with the indication of what kind of a day it was, e.g., clear, partly cloudy or cloudy.

The sum of heat provided by passive solar heating, body heat and internal gains was subtracted from the heat loss calculations to determine the net heat required by the building for each week, month and the entire heating season. This net heat requirement was divided by the potential heat contained in the wood burned to obtain the overall system efficiency. The wood was weighed before and after oven drying tests to determine its moisture content. The potential energy in the wood was calculated as a function of the actual moisture content and the fuel type.

While calculation of the heat required for above ground structural components is straight forward and accurate, determining the energy required for below grade concrete structures is difficult to determine accurately. Two models were utilized for the below grade heat loss calculations. Mike Chapman, Program Engineer for DNRC, calculated the below grade heat loss using the Mitalas, Canadian method, while the analyst, Wrench, used a fixed number of BTU/sq ft method. Both are reported.

Fireplace Insert

A double walled, conventional fireplace heat-o-lator type insert was built into the conventional masonry fireplace. The unit was modified to allow the opening and closing of the chimney flue by a recessed lever mounted on the front of the insert. Sealed and removable cast iron doors were installed on the front. In the rear of the unit a cast iron chamber provides a path for the products of combustion to leave the lower portion of the sealed, six sided firebox and vent to the chimney flue. External air is brought in for combustion and preheated. Centrifugal blowers bring room air in from the floor and pass it around the double walls of the firebox and then exhausted to the room at the top of the unit. Once in operation the rate of heat production is controlled by the volume of combustion air. The doors can be opened and removed for conventional fireplace use.

Monitoring

The weight of the wood loaded and time of loading was recorded. Every 30 minutes the temperature of the cast iron radiant surface and the convection air was recorded. As before,the moisture content of the wood was determined prior to calculating the potential energy contained in the wood. The sum of the actual heat delivered by radiant and convection air was divided by the potential energy contained in the wood fuel to calculate overall efficiency.

Results

Integrated Energy Production/Management System

Using the Mitalas model for below grade heat loss, the overall efficiency in delivering the potential heat contained in the wood was 73%. Using the fixed number of BTU/sq ft model, the overall efficiency was 87%.

Fireplace Insert 85% to 90% overall efficiency was obtained.

SECTION 1. PURPOSE OF THE PROJECT AND CONTRACT AGREEMENT

A contract agreement was made and entered into the 1st day of January, 1984, between the Montana Department of Natural Resources and Conservation, 32 South Ewing, Helena, Montana 59620 and Wrench & Associates, 295 Highland Drive, Kalispell, Montana 59901. The purpose of the contract agreement was to lessen the state's reliance on fossil fuels pursuant to Title 90, Chapter 3, Part 1, MCA and the Administrative Rules adopted thereunder.

SECTION 2. SCOPE OF THE PROJECT

Under the terms of the Contract Agreement, WRENCH & ASSOCIATES conducted performance monitoring during the 1983-84 heating season at the location listed below:

295 Highland Drive
Kalispell, Montana 59901

The intent of the performance monitoring is as follows:

1. To determine the overall efficiency of an integrated energy production management system presently installed in the Contractor's home, and;
2. To determine the overall efficiency of a fireplace insert previously built by the contractor with respect to heat output and cost in different modes of operation.

More specifically, the Contractor shall perform the tasks reported on in the following sections 3-8 of this report.

SECTION 3. SYSTEM DESCRIPTION

3.1 GENERAL DISCUSSION

During the late 1960's a 3,600 square foot home was designed and built to test low cost methods of energy conservation. The results of monitoring verified the design calculations. Next, a home designed to generate energy efficiently was designed using the previously proven conservation design. Subsequent homes and energy systems were designed, constructed, monitored and tested, based on the lessons learned on previous homes and systems.

After approximately 15 years and several homes, the current 3,600 square foot home was designed and constructed. Low cost, conventional construction techniques and materials were used for both the home and energy system. The goal was to be able to build a home for no additional costs, when compared to comparable, conventional construction and to use renewable energy as the heat source. Further, the requirement was not to pay any more annual fuel costs than the fossil fuels replaced amd hopefully,significantly less amounts.

This home was designed to use wood as the renewable energy. This was selected for the sole reason it was the most cost-effective renewable energy fuel available in Kalispell. Solar, geothermal or other renewable energy sources could just as easily been designed into the system if they were locally available.Their utilization would be relatively simple to design & build.

The technology used to produce the results shown in this report are easily applicable to new and retrofit construction. This applies to either the home or the commercial/industrial application.This report documents the effects.

The fireplace insert resulted from the frustration of trying to obtain a commercially available unit that could be used to enjoy the beauty of a fire as well as provide heat efficiently. Most of the units available protruded from the fireplace and were, in my opinion, very ugly & costly.

Applying some fundamental laws of physics and common sense, I designed an insert that should cost the same as any other available one, be extremely efficient, fit flush into the fireplace and allow the aesthetical enjoyment of an open fire. DNRC approved my grant application to design, build and initially test the unit during the 1981-82 time period. It is this insert that was tested and reported on in this report.

3.2 SYSTEM DESCRIPTION: INTEGRATED ENERGY PRODUCTION/MANAGEMENT SYSTEM

Shown below is a picture of the home monitored. It is sited on the top of a hill where high winds come out of the East from Glacier National Park each winter. Note the windows facing the weather from the northeast.

There is nothing unusual about the design and construction of the home, except for the following features. They are quite critical.

(1)The walls and ceilings have an absolute moisture seal installed.A piece of clear plastic is stapled to the ceiling joists prior to installation of the sheet rock. The outside walls were covered with a piece of clear plastic over the cdx plywood sheeting and then covered with the tar paper. When it was apparent the wall structure was completely dry another sheet of clear plastic was installed on the inside of the wall prior to the sheet rock installation. The plastic was overlaped 1½ to 2 feet on the walls and where it met the ceiling. Regular staples were used for installation.

(2) The chimney was installed in the center of the building for the wood furnace. When it entered the unheated attic area 18 inches of fiberglass blanket insulation was installed to prevent condensation of cresote. The return air is passed from the ceiling down a masonry chamber around the chimney to act as an air-to-air heat exchanger to recover flue heat. The resulting masonry makes a thermal mass, 2 ft x 4 ft x 16 ft to store heat.

The walls are standard 2x4 construction. 3½ inches of fiberglass blanket insulation is installed. The ceiling has 9½ inches of fiberglass blanket installed. Each recessed light fixture has no insulation for 6 inches around the edge for fire protection. There are 18 recessed fixtures so a sizeable area of the ceiling is without insulation. The below grade concrete is moisture sealed with tar and has no insulation. The home has 1,800 square feet on each floor, for a total of 3,600 square feet of heated space.

The heating system is designed and constructed using standard, commercially available components. The system was sized using a heat loss analysis to determine the average, not instantaneous, BTUH during the coldest time of the year. With a night time set back a furnace capable of delivering heat at the rate of approximately 45-50,000 BTUH would have been required. The Riteway brand, Model 37 was selected for two reasons. One, it had a 30 year history of high efficiency, no problem operation and, two, it was rated at 73,000BTUH, the closest available to the design requirement.

It should be noted that almost all heating plants are sized for the instantaneous heating requirement so as to provide rapid heating. Efficient conversion of potential energy into delivered energy is obtained by constant operation of a furnace,not cyclic operation. This allows ideal temperatures to be obtained and maintained. The furnace was sized to constantly produce heat at the rate the building was losing it to the outside on the average coldest day of the year. This, while unorthodox, is extremely critical.

The next step was to remove the heat at the rate it was being produced without reducing optimum furnace temperatures. This was achieved by the installation of a Honeywell brand, model L4064 B1469 combination fan and limit control in the air chamber above the furnace. When the air surrounding the wood furnace reaches 125°F the fan is turned on. When the temperature drops to 95°F the fan is turned off. A standard sheet metal forced air duct system was installed. The duct size and room openings were sized to deliver the number of BTUs the room lost to the outside each hour. Ducts were generally connected to floor registers under outside windows.

One of the key portions of the design is the return air system. A very large plenum is installed in the ceiling to collect the return air. Insulated, to prevent loss to the attic,air is sucked from the room, passed around the chimney from the furnace to recover the heat contined in the flue gases and returned to furnace. The ceiling location for the return air does two things. First, a fairly equal temperature gradiant is maintained throughout the entire volume of the room for comfort and no temperature buildup occurs at the ceiling level. This last item is important, as it significantly reduces the differential temperature between the ceiling and the attic and less insulation is required.

A small, 20 KW electric furnace was installed in the system. This size was selected as it had a 1/3 HP blower required to provide the correct CFM of air movement. It has the air filter and the backup to keep the home from freezing in a Montana winter when you are not at home. It also has the 24 VAC electrical power required to run the controls. Wood is quite satisfactory when you are home. However, you do not want the home to freeze when you are away. A flip of a switch converts the system from the wood furnace to electric. When leaving for a winter trip the thermostat is set to 50°F and the switch set to electric heat. The cost proved minuscule

The controls are also standard. Two thermostats are used. One is set for the temperature desired during the day, 70°F, and the other for the night time temperature, 62°F. A clock operates a relay that switches between the two. Some initial experimentation was required to have the home warm when you get up in the morning and still warm when you go to bed at night. A manual override was provide for the few times you either wished to stay up late at night or get up early in the morning. These thermostats controlled a motorized damper. When heat was signaled the damper opened to allow the maximum volume of combustion air to be available to the furnace. The thermostats had heat anticipator circuits so as to not allow the rooms to be too cold before heat is supplied. When the damper motor is shut off the source of combustion air would be eliminated and the fire would go out. To prevent this a bimetalic heat sensor maintains just enough oxygen to prevent the fire from going out. This system has proven to be quite ideal for the several years it has been in operation.

A word needs to be said about the selection of the wood furnace. A quite extensive research project was conducted to determine what was available in wood burning technology, literally, throughout the world. A paucity of test data, coupled with unwarranted claims on many available units made selection initially difficult. Many years were required to come to a justifiable selection. It was necessary to go back to the text books to study the physics and chemistry of pyrology. Wood is essentially comprised of water, lignum and cellulose. After driving off the water the solids are converted into a gas. When mixed with oxygen and heated to the temperature of spontaneous combustion oxidation, burning, occurs. The gases expand due to the pressures created. In most fireboxes having a top opening only partial combustion occurs, due to the gases cooling below a critical temperature.

It was apparent, if higher efficiencies were to be obtained, the gases had to be recovered and burned again before venting to the atmosphere. This is accomplished by sealing the top of the firebox and providing an opening at the bottom leading to the chimney. The expanding gases are passed through the coals, where they are reheated and mixed with additional oxygen and then reburned as they pass through an afterburner chamber. Ideally, only moisture and carbon dioxide will be vented from an efficient firebox. As it turned out the Riteway Company had been using this principal for at least 30 years. After searching out users it was apparent the hardware was reliable and indeed efficient. This is the reason the Riteway brand was selected.

Air from outside the building is brought to the region of the exhaust flue. It is passed around the flue and after burner chamber for heating.As heating a gas expands it, a portion is vented into the building. This serves to make a positive pressure which reduces infiltration air around doors and windows. The use of outside combustion air dramatically reduces the building's heat requirements by not using already heated air for combustion.

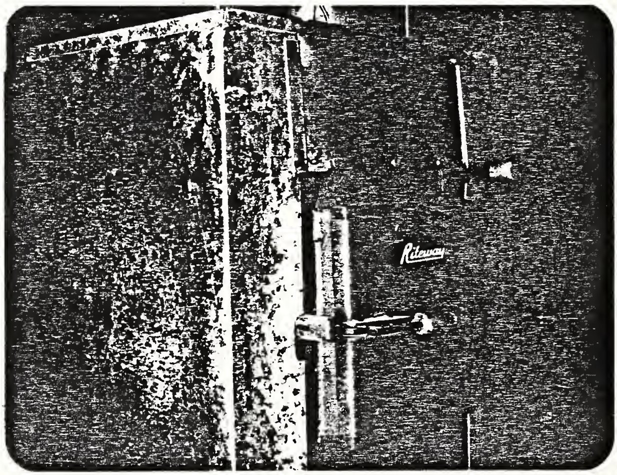
Cast iron pipes are installed in the back of the firebox to preheat the domestic hot water. The water is circulated by thermosiphoning action most of the time to gradually raise the temperature of a 50 gallon pre-heat tank. When the furnace produces hot water at too high a rate a aquastat senses the temperature and a pump is turned on to circulate the water. During the peak of the winter most of the domestic hot water is supplied by the wood furnace. The pre-heat tank supplies water to a standard hot water heater to insure a constant supply temperature.

Lastly, an automatic humidifier is installed. Unfortunately, it was not yet hooked up during this monitoring program.

Immediately following this page are a series of color photographs showing this system.

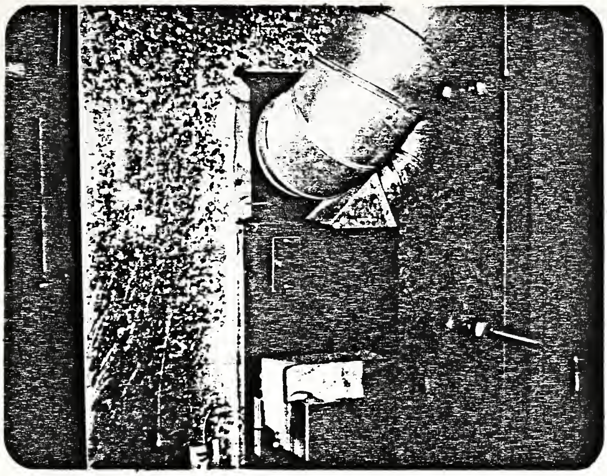
SYSTEM CONTROLS

On the left is the Humidity Control. The Day Time Temperature is in the center. On the right is the Night Time control and the backup System These are located in the main living portion of the home.



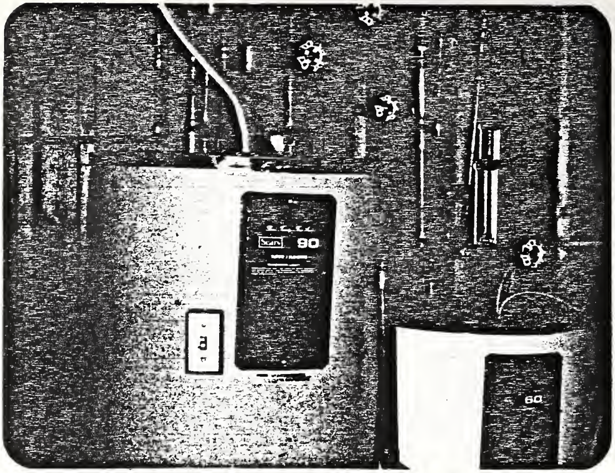
MAIN WOOD FURNACE

Shown is the loading door. Note the upper wooden handle. This opens and closes the top of the firebox to the chimney to prevent smoke in the room during loading. The sheet metal is a path for forced air to go around the stove. The size is 24 in x 48 in.



SIDE VIEW-WOOD FURNACE
On the right side the hot water pre-heat pipes enter the fire box. The lower center is the electric damper motor. The black knob directly above is the bi-metalic control to prevent the fire from going out. The shiny 3 in. pipe, below the stove pipe, is the combustion air as it enters the first pre-heat area. Above and slightly to the left of the black knob is a angular sheet metal opening where heated external air is bled into the room for pressurization of the home.

BACKUP ELECTRIC FURNACE
This supplies heat for winter vacations, a air blower and air cleaner. The day-night clock, used to switch thermostats, is in upper left. Note the clean, small and simple lines .



HOT WATER HEATER & PRE-HEATER

The tank on the right is a 50 gallon pre-heat standard hot water heater. It was considerably cheaper to buy a hot water heater than to purchase a pre-heat tank. Most of the plumbing shown, as well as that not in the picture, was initially installed to allow various testing of the system Only a few items are required for normal operation.

The vertical pipe entering from the bottom center, comes from the output of the wood furnace (see top pipe in previous picture). Following the vertical T a pressure/temperature relief valve is installed. There are three of these for safety, one for each tank and one for the furnace loop. The shiny, rectangular devices are immersion thermometers to measure the temperature of the water entering and leaving the pre-heat tank. ¼ in down and 1¼ inches from the top right corner is a green divice. This is an automatic air release valve. This automatically releases air from the system to prevent vapor locks which could stop the thermosiphoning. Out of the picture are the automatic controls and pump to circulate the pre-heated water.

3.3 SYSTEM DESCRIPTION: FIREPLACE INSERT

As this system was developed with Grant funds·An indepth description can be obtained from DNRC files as follows.

Grant Title: "Development of an Efficient Fireplace
Insert Stove"

Grant Agreement No. 322-811

Effective Date: 3/18/81

Final Report Date: April 15, 1982

Grant Amount: $6,500

Grantee: Richard G. Wrench

Grantor: Energy Division, DNRC

A commercial, double walled fireplace insert was modified. A cast iron chamber was welded to the back portion and vented to the area above the flue damper, which had a space cut out to accomodate the chamber. The chamber is open to the firebox area at all times approximately six inches above the floor of the unit. The cross section of the chamber was approximately 20 square inches. The unit was built into the masonry identical to any other insert. Twin blowers were installed in the hearth. They suck in air from the floor, blow it around the firebox in the double walls and out into the room. Combustion air is brought in from outside the building. Before entering the firebox it is heated by radiant energy from the coals to the pipes carrying it. Removable, cast iron doors convert the insert from an air tight stove to a conventional fireplace. The doors set on pins and can be removed in seconds. Each is fitted with a recessed seal to maintain an airtight seal when closed. A recessed lever opens and closes the flue damper from the room.

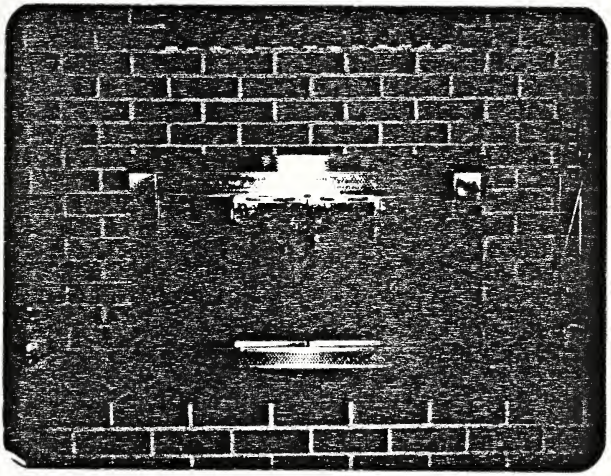
Theory of operation: The fireplace insert is capable of three modes of operation. With the cast iron doors removed, a few second process, the unit functions as a regular fireplace. Glass doors can be closed to view the fire and outside combustion air used. If desired the glass doors can be folded out of the way, a metal screen pulled in place and the fire felt.

With the glass doors in place and the blowers on, the unit functions like a conventional insert. Combustion air is provided from outside the building. The fire can be seen,not felt, and heat is provided by the forced air blown through the double wall around the firebox.

The third and primary mode of operation results when the cast iron doors are closed, sealing the front air tight. A lever mounted on the front of the unit seals off the top of the firebox. The fire is "nested" in a bed of ashes directly on the firebrick floor. This is an absolute necessity to prevent air and gas flows from reducing the operational temperatures required to sustain the distillation of the wood and gas temperatures above the coals. Pre-heated external combustion air is mixed with the gases. Partially burned gases, not being able to escape from the sealed top of the firebox, are forced back through the bed of hot coals. They are mixed with hot oxygen and reburn on their way out the opening the chamber provides from the bottom of the unit to the chimney above. The blowers constantly remove the heat produced. To add fuel the lever is pulled to open the top to the chimney. The cast iron doors can then be opened without any smoke coming into the room.

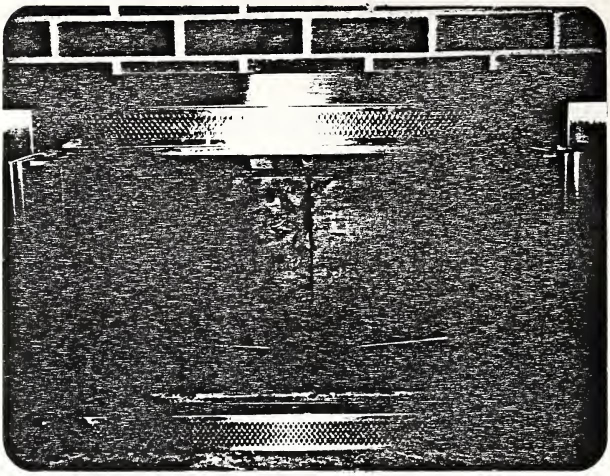
Initially, it was thought efficiency came about due to the afterburner principal. It was found no combustion occurs in the chamber. Efficiency is achieved by closing off the top of the firebox and reheating the partially burned gases. They appear to be reburning in the primary combustion chamber.

Immediately following are a series of color photographs showing the unit.



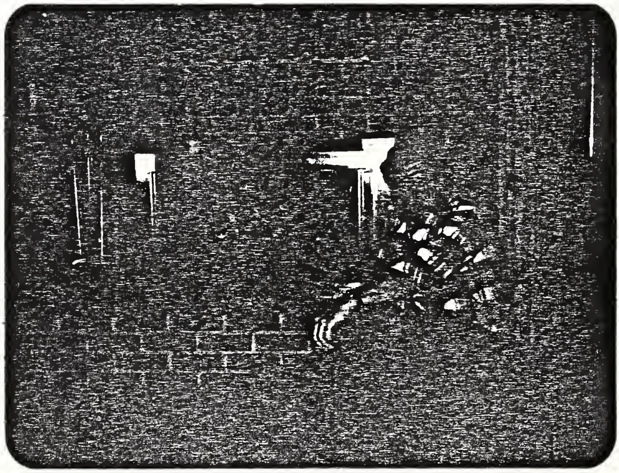
FIREPLACE INSERT

The fire screen has been pulled out of the way to show the cast iron doors behind the fold away glass doors. When the fire screen is pulled across, the black castiron doors are not apparent and the unit has aesthetic appeal. Note the insert fits flush with the surface opening. It does not protrude into the room at all. Only the commercial screen protrudes. Room air is sucked into the hearth, on the sides out of the picture, and is blown into the room from the openings above the insert.



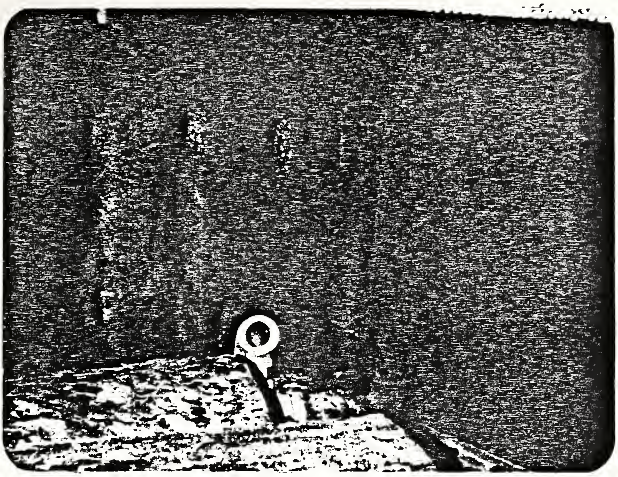
INSERT OPERATING IN PRIMARY MODE

The glass doors are folded out of the way so the radiant heat generated by the black, cast iron doors can enter the room. These doors are sealed air tight to the frame (see picture below), Note the small, light brown rectangular knob at the center top of the doors. This closes the top of the insert to seal the firebox from the chimney. It folds out of sight if the insert is used for a conventional fireplace with the doors removed.



CONVENTIONAL FIREPLACE MODE

The cast iron doors remove in seconds by lifting each from the pins. The light from the flash made the door seal stand out. Normally, with the screen pulled to the edge of the opening, you would not be aware of the insert being installed at all. A normal fire can be enjoyed in this mode.



INSIDE THE INSERT

When the insert is in operation all six sides are sealed. The only opening to the chimney is through the rectangular opening shown on the right with a pipe leading to it. This pipe was orgionally installed to supply heated oxygen to the afterburner. It was sealed off during the test program. The grey pipe opening is one of the jets of heated external combustion air. The pipes are standard water pipes. They are installed so the bed of coals are always heating the oxygen.

Note the corrugation in the sides of the insert. This is extremely important to allow for expansion during operation without metal failure. Also note the height of the lower opening for the vertical chamber. This must be placed low enough to insure the partially burned gases can be forced back through the coals and not too low as to increase the firebox pressure and stop the automatic flow of oxygen through the system. This is extremly important. The spacing of the opening and the cross sectional size are critical for successful operation. While it looks quite simple, this is the secret to the operational efficiency.

SECTION 4. MONITORING PLAN

General Discussion

As there are two unique systems, a separate monitoring plan was required for each as follows.

Integrated Energy Production/Management System

Generally, the fuel was allowed to burn 60% to 75% of the prior load before another load was placed in the firebox. Fuel was loaded each morning at 8 A.M. and again at 8 P.M. Whenever possible fuel was also loaded at 12 noon as well. Each day the following measurements were taken and recorded.

- Weight of the fuel loaded
- Time the fuel was loaded
- Outside air temperature every four hours
- Inside air temperature every four hours
- Temperature of cold water supply daily
- Temperature of the pre-heat domestic hot water tank every four hours
- Type of day: clear, partly cloudy or cloudy
- Wind conditions daily
- Internal gain factors: # people, lighting, cooking etc., daily.

During the day the temperature was taken from on site thermometers. During the night the temperature of the weather station at the international airport, located a few miles away, was used as the 12 midnight temperature. To determine internal gain factors the number of people and their level of activity was recorded. The time and wattage of electrical appliances & lights was recorded. The time of a shower and volume of water was recorded. The volume was determined by averaging the time required to fill a five gallon bucket five different times. Initially, the mixed hot and cold was used. Then the hot was shut off to determine the volume of cold water vs time. Careful attention was paid to each detail to insure an accurate internal gain.

The external air temperature was determined by averaging two outside thermometers, located four feet down from the eves and out of the sun and wind. The internal temperature was taken by averaging two wall mounted thermometers and a hand held thermometer moved from various room locations. The water temperature was determined by injection thermometers installed in the plumbing where the water flows. A hydrostat was surface mounted to the hot water coils six inches from the point the pipes leave the furnace. An air temperature sensor was placed in the chamber above the wood furnace to turn on and off the air blower.

Fireplace Insert

Each time a test was run a nest of ashes was prepared on top of the fire brick, except for the raised hearth tests. Paper and kindling was used to start the fire. The amount of fuel used to start the fire was recorded. The following data and measurements were recorded.

Weight of fuel loaded
Time the fuel was loaded
Mode of operation
Inlet air temperature
Outlet air temperature
Surface temperature of the radiant cast iron doors
Volume of convection air flow

The volume of air flow had been determined during the previous testing and was assumed to be the same. The temperature of the air flowing into the insert was the average of two thermometers placed in the center of the inlet grill on each side. The temperature of the outlet convection air temperature was the average of three and sometimes four thermometers placed in the air stream leaving the unit. The temperature of the cast iron doors came from a contact thermometer placed on the horizontal center line of the cast iron doors in an area approximately one third the distance in from the sides.

4.1 MONITORING EQUIPMENT

Integrated Energy Production/Management System

Inside thermometers	Honeywell multistage mecury thermostat/thermometer No. T-872C-1038. Accuracy ± 0.1°F
	Wesco Electric singlestage mecury thermostat/thermometer. Accuracy ± 0.5°F
	Hand held mecury thermostat, non-adjustable Accuracy ± 1°F
Furnace sensor	Honeywell Super Tradeline combination fan & limit control No. L-406413-1469, with adjustable limit stop and differential fan control. Accurcy ± 1.5°F
Water thermometers	Mfg. unknown 40°F to 260°F. Accuracy ± 1.5°F
Aquastat	Honeywell No. LA409B-1071-1. Accuracy ± 1°F
Scales	Tolledo meat scales
Outside thermometers	Bimetal standard dial adjustable. Accuracy ± 1°F

Fireplace Insert

Scales	Tolledo meat scales
Convection air Thermostat	American Standard No. CC-58001, bi-metal Accuracy ± 1.25°F for inlet air temperature Bimetal, sealed dial, 400°F limit. Accuracy ± 1.5°F
Radiant surface Thermostat	Bimetal contact. 1,000°F limit. Accuracy ± 10°F

4.2 FUEL ANALYSIS

The fuel used was dry standing larch. For those unfamilar, this is a tree that has been standing sometime after it died. The wood is sound and has significantly less moisture content than a green fuel. The overall efficiency of both systems depends on very accurately determining the potential energy in the fuel.

To insure the accuracy of the fuel analysis the following individual was contacted:

Mr. Edwin J. Burke
Assistant Professor of Wood Products & Utilization
School of Forestry
University of Montana
Missoula,Montana 59812

Professor Burke was most gracious to guide the analysis of the fuel and provide the following facts, which are replicated here for general use.

FUEL PARAMETERS

Average moisture content, MC, of dry standing larch snag:

Winter = 30%
Summer = 20%

Average weight of a cord of larch @ 15% MC = 2,966 pounds

Stacked green larch will have 35% MC after being outside a winter @ 75% MC initial

Stacked dry larch will have 15-20% MC after being outside a winter @ 20-30% MC initi

Wood weight can be computed from volume by using a density value of 30.5 lbs/ft^3. Note: this assumes a solid volume, not the stacked volume. For example, a solid cord would occupy 85 cubic feet, where a stacked cord is 128 cubic feet.

Moisture content is determined by placing a specimen in an oven @ 215^{O}F until weight loss stops using the following steps:

Weigh green

Oven dry

Weigh oven dry

Perform this calculation

$$\text{M.C.\%} = \frac{\text{greenweight} - \text{O.D. weight}}{\text{O.D. Weight}}$$

Larch will have a heating value of 8,400 BTU/lb @ zero MC. This includes the heat of condensation of water liberated from the wood during pyrolysis. The formula to determine heat value for practical moisture contents is:

$$H @ \overset{*}{MC} = H_{OD}\left(\frac{100 - \left(\frac{\overset{*}{MC}}{7}\right)}{100 + MC^{*}}\right)$$

* MC Must be a whole number

An example is shown on the next page of this calculation.

Example of the heat value for a pound of larch having 15% moisture content

$$H_{@\ 15\%\ MC} = H_{OD}\left(\frac{100 - (\frac{15}{7})}{100 + 15}\right)$$

$$H_{@\ 15\%\ MC} = 8{,}400\left(\frac{100 - 2.14}{115}\right)$$

$$H_{@\ 15\%\ MC} = 8{,}400\ (0.85)$$

$$H_{@\ 15\%\ MC} = 7{,}140\ \text{BTU/lb}$$

Thus a pound of larch with 15% moisture content has a heat value of 7,140 BTUs. The water liberated during pyrolysis can not be recovered in a furnace.

During the 1983-84 heating season the wood was tested, as just described, nine times for moisture content. The results of the tests are:

14.417% MC
14.661% MC
14.656% MC
14.663% MC
14.703% MC
14.853% MC
14.951% MC
14.890% MC
14.906% MC

Calculation of the potential heat value of the fuel burned follows. The average moisture content of the wood burned was 14.744%. As the formula requires a whole number for moisture content, 15% will be used.

$$H\ @\ 15\%\ MC = H\ OD\ (8{,}400)\left(\frac{100 - \frac{15}{7}}{100 + 15}\right)$$

H = 7,140 BTU/lb x 0.9* = 6,426 BTU/lb potential heat in the fuel.

* A 10% loss is assumed for H_2O/CO_2 removed during pyrolysis & not recovered.

Wood Analysis, continued:

Following is a listing of the amount of fuel burned and the potential energy in the wood. Potential energy is 6,426 BTU/lb x pounds burned.

		NIGHT TIME		DAY TIME		24 HOUR TOTAL
TIME	DAY	LBS	POT. BTUs	LBS	POT. BTUs	POTENTIAL HEAT
Dec. 1-7	7	398	2,557,548	620	3,984,120	6,541,668
Dec. 8-14	7	327	2,101,302	530	3,405,780	5,507,082
Dec. 15-21	7	446	2,865,996	889	5,712,714	8,578,710
Dec. 22-31	10	826	5,307,876	1,148	7,377,048	12,684,924
Dec 1-31	31	1,997	12,832,722	3,187	20,479,662	33,312,384
Jan. 1-7	7	302	1,940,652	413	2,653,938	4,594,590
Jan. 8-14	7	364	2,339,064	602	3,868,452	6,207,516
Jan. 15-21	7	473	3,039,498	720	4,626,720	7,666,218
Jan. 22-31	10	460	2,955,966	702	4,511,052	7,467,012
Jan. 1-31	31	1,599	10,275,174	2,437	15,660,162	25,935,336
Feb. 1-7	7	362	2,326,212	502	3,225,852	5,552,064
Feb. 8-14	7	278	1,786,428	455	2,923,830	4,710,258
Feb. 15-21	4	147	944,622	298	1,914,948	2,859,576
Feb. 22-29	8	367	2,358,342	576	3,701,376	6,059,718
Feb. 1-29	26	1,154	7,415,604	1,831	11,766,006	19,181,610

Wood Analysis, continued:

		NIGHT TIME		DAY TIME		24 HOUR TOTAL
TIME	DAY	LBS	POT. BTUs	LBS	POT. BTUs	POTENTIAL HEAT
Mar. 1-7	7	299	1,921,374	404	2,596,104	4,517,478
Mar. 8-14	7	266	1,709,316	349	2,242,674	3,951,990
Mar. 15-17	2	70	449,820	66	424,116	873,936
Mar. 22-31	9	375	2,409,750	420	2,698,920	5,108,670
Mar. 1-31	25	1,010	6,490,260	1,239	7,961,814	14,452,074
Apl. 1-7	7	265	1,702,890	339	2,178,414	3,881,304
Apl. 8-13	6	276	1,773,576	187	1,201,662	2,975,238
Apl. 1-13	13	541	3,476,466	526	3,380,076	6,856,542

HEATING SEASON/TEST PERIOD TOTALS

Dec. 1-Apl.13	126	6,301	40,490,226	9,220	59,247,720	99,737,946

Summary of the above indicates 15,521 pounds of wood was burned for a potential of 99,737,946 BTUs of heat contained in the wood.

Weight vs Volume fuel consumed

The volume of the wood was measured each month as well as the weight burned.

December	1.73 Cord	
January	1.368	
February	0.855	By Volume
March	0.8685	
April	0.50	
	5.3215 Cords burned by volume measurements	

15,521 lb ÷ 2,966 lb/cord = 5.2329 Cords burned by weight

4.3 SETUP AND CHECKOUT

Integrated Energy Production/Management System

This system had been in operation for several years. The bugs had been worked out prior to the monitoring program. Thermometers had to be installed outside the house and checked with the weather service to verify the temperature was accurate. The scales used to weigh the fuel had to be verified for accuracy. The moisture testing of the wood took some time to develop the assurance accurate results were being obtained. Many letters and conversations between Mr. Michael Chapman, Program Engineer, Energy Division, DNRC, Professor Burke, School of Forestry, University of Montana and the Contractor, Richard G. Wrench were necessary to be assured of an accurate fuel analysis. Two weeks before the data was formally recorded, tentative data sheets were compiled, modified and checked to assure requisite data would be collected in a proper manner.

Fireplace Insert

A series of test burns were conducted prior to the actual recording of data. No unexpected problems occured. The basis of the initial testing was to determine the best places to set up the various thermometers to be assured of representative temperatures.

Both systems were carefully pre-tested to be assured of accurate monitoring during the test period. There were no problems as a result.

SECTION 5. DATA COLLECTION

5.1 INTEGRATED ENERGY PRODUCTION/MANAGEMENT SYSTEM

Each day the following data was recorded:

1. Overnight low temperature
2. 8 A.M outside air temperature
3. 12 Noon outside air temperature
4. 4 P.M. outside air temperature
5. 8 P.M. Outside air temperature
6. Day time average outside air temperature
7. Night time average outside air temperature
8. Type of day experienced: clear, partly cloudy, or cloudy
9. Wind level experienced
10. Average of the day time temperature in the home
11. Average of the night time temperature in the home
12. Weight of the wood loaded
13. Time the wood was loaded
14. Total weight of the wood burned during the day time
15. Total weight of the wood burned during the night time
16. Night time differential temperature, building to outside
17. Day time differential temperature, building to outside.
18. Domestic water temperatures throughout the system

The raw data collected is contained in the appendix of this report.

In addition to the daily data, the chimney was inspected for cresote buildup, stack pollutants and temperature. As a matter of preventive safety, the chimney was cleaned every six weeks. This is a few minute process. At the end of the heating season the cresote was collected. Approximately 2 gallons of scraped off, solid cresote resulted from the burning of 5½ cords of larch.

A contact thermometer was used to periodically measure the flue gases approximately 12 inch into the stove pipe prior to the entry into the flue. The normal operating temperature was between 300°F and 700°F. This varied with the heat demands of the home as a function of the prevailing differential temperatures between the outside air and the building. As a point of interest, the flue gas would reach 900°F if the ash clean out door was opened. This would allow excessive oxygen into the firebox.

When the motorized damper was closed and only the bimetalic damper in operation (to keep the fire from going out) the flue gases would range from 160°F to 180°F. Flue gase were then in the 160°F to 180°F when the stove was shut down and in the 300°F to 700°F during heat production. These were the temperatures prior to the flue gases entering the air-to-air heat exchanger. A thermometer was placed 18 inches down into the chimney before venting to the atmosphere to measure the temperature of the flue gas. These gases, both the fire place insert and the integrated energy production/management system, consistently measured between 100°F and 120°F throughout the entire test/monitoring program.

It was quite apparent that the moisture dropplets were being moved by the flue gas in motion. There was no condensation of any kind on either system inside the flue. If a foreign object were placed in the stream it immediately became wet. Lastly, the flue gases were essentially white vapor.

5.2 FIREPLACE INSERT

Each time the insert was tested the following data was recorded:

1. Type of test being conducted
2. Date of the test
3. Specific event/ mode
4. Time of each occurance/event
5. Elapsed time
6. Temperature of the cast iron radiant surface
7. Inlet, convection/blower air temperature
8. Outlet, convection/blower air temperature
9. Differential temperature of inlet/outlet air .
10. Weight of fuel loaded
11. General comments & observations

As soon as the test was completed, the following data was calculated and entered on the raw data sheet. This was used to determine if additional tests in the same mode were required.

1. Rate, BTUH, of radiant heat generation
2. Number of radiant BTUs delivered in the time period of 30 minutes
3. Rate, BTUH, of convection air heat generation
4. Number of BTUs delivered by convection air each 30 minutes
5. Sum of radiant & convection air BTUs delivered each hour
6. Total weight of fuel burned for the test
7. Total BTUs actually delivered by radiant & convection sources.
8. Overall efficiency of the insert in the tested mode.

SECTION 6. DATA ANALYSIS

6.1 GENERAL DISCUSSION

Before any calculations or conclusions were attempted, DNRC had to issue prior approval of all assumptions, formulae, methods etc. These were submitted along with sample calculations for approval. Except for the calculation of below grade concrete heat loss, there was complete agreement on all matters. On the latter, below grade heat loss calculations, both methods are discussed herein and the resulting effects shown. It should be pointed out below grade heat loss predictions are still in the art phase. No absolute method exists. Because of this uncertainty the accuracy of the overall efficiency of the integrated energy production/management system depends on the method used. Both methods are presented for the reader to personally consider in whatever judgement form applicable.

6.2 EQUASIONS GOVERNING ENERGY TRANSFORMATIONS

Following are the various formulas used:

6.2.1 Moisture content in the fuel

Moisture content in the fuel is determined by placing a specimen in an oven @ 215°F until weight loss stops using the following steps:

Weigh green

Oven dry

Weigh oven dry, OD

Perform this calculation

$$\text{M.C \%} = \frac{\text{green weight} - \text{O.D. weight}}{\text{O.D. Weight}}$$

6.2.2 BTU/lb @ Moisture Content

BTU/lb of fuel burned are determined by the following formula:

Assumption: H @ 0% M.C. larch = 8,400/lb $= H_{OD}$

$$H @_{M.C.} = H_{OD} \frac{100 - (\frac{MC}{7})}{100 + MC}$$

Where M.C. is always a whole number

6.2.3 Radiant heat

The following formula was used to determine the number of BTUs radiated into the room from the black, cast iron fire place doors:

$$Q^{\cdot} = A \times E \times S \times (T_s^4 - T_a^4)$$

Where:

$Q^{\cdot}$ = BTUH

E = 0.90038

A = Area of radiant surface = 5 square feet

S = S.B. Constant = $1.713\ 10^{-9}$

T_s = Surface temp. of cast iron doors in $^{O}F + 460^{O}F$

T_a = Ambient air temp in $^{O}F + 460^{O}F$

6.2.4 Convection heat

The following formula will be used to determine the number of BTUs delivered into the air space by the flow of air around the fireplace insert:

$Q^{\cdot}$ = BTUH = Density of the air x volume of air (CFM) x specific heat of the air x (temp. of air out - temp. of air in) x 60 minutes.

Where:

Density of the air = 1/17 (range is 1/13.398 to 1/17)

Volume of air moved = 285 CFM (Previously determined)

Specific heat of air = 0.35 @ 20% humidity (range is 0.24 to 0.4)

Delta T = As measured

60 = Conversion of minutes to hours for BTUH

6.2.5 Building heat loss

The building heat loss will be determined using the following formula and methods . the ASHRAE, Handbook of Fundamentals is used as the source of values and equasions. The actual materials used in the construction of the building will be used. (Note: the contractor also built the home personally)

$Q^{\cdot}$ = BTUH = U x H x A x Delta T + infiltration

Where:

$$U = \frac{1}{R_t} = \frac{1}{R_1 + R_2 + R_3 + \dots R_n}$$

H = A one hour period of time

A = The area being evaluated in square feet

Delta T = The difference in the actual measured inside and outside air temperature

The infiltration losses will be computed separate from the conduction loss through the building components.

6.2.6 Solar Gain

The amount of heat delivered into the building from solar energy will be calculated as follows:

Energy from the sun as specified in the Montana Solar Data Manual, 1982 edition

The useable daily heat, # BTUs, will be calculated as follows:

$\dot{Q}$ Solar = BTU/day = BTU/sq ft x refraction index x atmospheric moisture reduction factor x collector transmittance x building component absorptance factor x number of square feet of collector surface.

Where:

BTU/sq ft = As published in Montana Solar Data Manual. ASHRAE CLEAR DAY TABLES USED FOR CLEAR DAY
50% of Clear Day assumed on a partly cloudy day
Zero assumed on a cloudy day

Refraction = 1.08 Dec- Mar. & 1.05 in April per data in Montana Solar Data Manual

Atmosphere = 10% reduction from Flathead Lake air moisture

Transmittance = 75% through double pane windows

Absorptance = 85%

Long wave heat loss not a separate consideration. This is calculated in the basic home's heat loss analysis

6.2.7 Overall efficiency

In both the Integrated Energy Production /Management System and the Fireplace Insert, the number of pounds of wood burned will be multiplied times the 6,426 BTU/lb, potential heat, to determine the overall potential heat. In the case of the Integrated Energy Production/Management System, the sum of the solar and internal gains will be subtracted from the sum of the building's conduction and infiltration losses. This net loss will be divided by the potential heat in the fuel burned to determine overall efficiency.

In the case of the fireplace insert, the actual heat delivered into the heated space will be divided by the potential heat contained in the fuel burned to determine overall efficiency.

6.2.8 Internal gains

Internal gains will be as actually measured.

6.3 INTEGRATED ENERGY PRODUCTION/MANAGEMENT SYSTEM DATA REDUCTION

6.3.1 Area of building components

The area of the building was measured in detail. In the interest of brevity, the components will be summarized here,

MAIN LEVEL	
Ceiling	1,744 sq. ft
Windows	229.89 sq. ft
Doors	20.125 sq. ft
Walls	1,373.985 sq ft

BASEMENT LEVEL	
Slab	1,715.5 sq ft
Conc. to soil	926 sq ft
Conc. to air	94.537 sq ft
Door	20.125 sq ft
Walls	710.549 sq ft

6.3.2 R & U of building components

R & U of building components, continued

Ceiling			
	½ inch gypsum board	R = 0.45	
	Plastic film	R = Neg.	
	9½ in blanket @ R 3.85"	R = 36.575	
	Total R	= 37.025	U = 0.027008
Windows			
		R = 1.724	U = 0.58
Doors		R = 2.03	U = 0.49
Walls			
	Outside film	R = 0.81	
	Felt	R = 0.12	
	Blanket 3½" @ 3.85 "	R = 13.475	
	Air space	R = 0.87	
	Inside film	R = 0.45	
	Total R	= 15.725	U = 0.06359
Slab	R= 0.319 in x 4 in	R= 0.319	U = 3.125
Conc. wall		R = 0.64	U = 1.5625

SUMMARY

Ceiling	1,744 sq. ft.	R = 37.025	U = 0.027008
Windows	273.716	R = 1.725	U = 0.58
Doors	60.375	R = 2.03	U = 0.49
Walls	2,084.534	R = 15.725	U = 0.06359
Conc. to air	94.537	R = 0.64	U = 1.5625
Conc. to soil	926	R = 0.64	U = 1.5625
Slab	1,715.5	R = 0.319	U = 3.135

6.3.3 Heat Loss Calculations

Conduction and Infiltration losses will be independently calculated and then combined.

6.3.3.1 Conduction Loss Calculations

Following is a compilation of the actual differential measured temperatures. The entries are in $^{\circ}F$ differential temperatures: "T inside - T outside"

TIME PERIOD	# DAYS	NIGHT TIME	DAY TIME	24 HOUR AVERAGE
Dec. 1-7	7	53.24	55.07	54.155
Dec 8-14	7	41.65	45.93	43.79
Dec 15-21	7	71.14	71.24	71.19
Dec 22-31	10	69.3	74.30	71.8
Dec 1-31	31	58.83	61.64	60.235
Jan 1-7	7	32.67	39.5	36.085
Jan 8-14	7	47.43	49.18	48.305
Jan 15-21	7	58.0	64.54	61.27
Jan 22-31	10	34.54	40.13	37.335
Jan 1-31	31	43.16	48.34	45.75
Feb 1-7	7	44.0	44.39	44.195
Feb 8-14	7	35.62	39.57	37.595
Feb 15-21	4	35.34	40.63	37.985
Feb 22-29	8	40.05	43.16	41.605
Feb 1-29	26	38.75	41.94	40.345
Mar 1-7	7	36.78	38.21	37.495
Mar 8-14	7	31.67	35.39	33.53
Mar 15-17	2	29.5	33.0	31.25
Mar 23-31	9	34.45	36.75	35.6
Mar 1-31	25	33.1	35.84	34.47

Actual differential temperatures, continued

TIME PERIOD	# DAYS	NIGHT TIME	DAY TIME	24 HOUR AVERAGE
Apl 1-7	7	29.62	32.21	30.915
Apl 8-13	6	32.84	33.7	33.27
Apl 1-13	13	31.23	32.96	32.095
HEATING SEASON AVERAGES				
Dec 1- Apl 13	126	42.1022	45.3833	43.74275

The average temperature, over a 24 hour period for the 126 day monitoring period was 43.74275°F. This was the difference between the temperature inside the building and that of the air outside.

Following is a summary of the conduction heat losses based on the average 24 hour measured differential temperatures just listed.

TIME PERIOD	# DAYS	24 Hr DELTA T	BTUs LOST BY CONDUCTION
Dec 1-7	7	54.155°F	5,864,095
Dec 8-14	7	43.79	4,966,079
Dec 15-21	7	71.19	7,339,977
Dec 22-31	10	71.8	10,561,213
Dec 1-31	31	60.235	28,302,397
Jan 1-7	7	36.085	4,298,523
Jan 8-14	7	48.305	5,357,256
Jan 15-21	7	61.27	6,480,535
Jan22-31	10	37.335	6,295,460
Jan 1-31	31	45.75	22,744,668

Conduction heat loss summary, continued

TIME PERIOD	# DAYS	24 Hr DELTA T	BTUs LOST BY CONDUCTION
Feb 1-7	7	44.195°F	5,001,168
Feb 8-14	7	37.595	4,431,286
Feb 15-21	4	37.985	2,550,365
Feb 22-29	8	41.605	5,459,170
Feb 1-29	26	40.345	17,336,826
Mar 1-7	7	37.495	4,420,685
Mar 8-14	7	33.53	4,077,159
Mar 15-17	2	31.25	1,108,464
Mar 23-31	9	35.6	5,472,647
Mar 1-31	25	34.47	14,852,145
Apl 1-7	7	30.915	3,850,596
Apl 8-13	6	33.27	3,475,400
Apl 1-13	13	32.095	7,340,973

HEATING SEASON AVERAGES

Dec 1- Apl 13	126	43.3833	88,806,380

During the 126 day monitoring period of 126 days the average differential temperature was 43.3833°F and 88,806, 380 BTUs were lost from the building due to direct flow through all the building's components. These figures were calculated using the formula for building heat loss shown in section 6.2.5, except concrete to the soil was computed at 5.682 BTU/hr/sq ft.

The slab was computed at 1 BTU/Hr/sq ft. These two numbers are based on historic losses of below grade through concrete.

Mike Chapman, Program Engineer, Energy Division, DNRC, conducted extensive analysis of this project using the Mitalas,1982, method of calculating basement heat loss from extensive work done by the Canadians. Mr. Chapman's work is done with technical excellence and in quite some depth. To include the complete works would require an appendix approaching this final report. You are urged to contact Mr. Chapman if interested.

6.3.3.2 Infiltration Loss Calculations

As there is no absolute way of assuring how many times each hour the volume of heated air is replaced, the calculations for infiltration will be done on a parametric basis. Thus, one can select the number of air changes appropriate for the circumstances and have the exact heat loss available. The following formula will be used to calculate infiltration losses.

$Q^{\cdot}_{\text{Infiltration}}$ = BTU/Month = 0.018 x (0.1 or 0.2 or 0.3 air change rate) x 24 hour x 14.295 cubic feet x Delta T x # day/mo.

The lower level is quite well sealed and is not extensively used. The upper level has three openings for entry and is in use constantly as well as venting for cooking, windows and air leakage around doors and windows. Therefore, the infiltration losses will be calculated separately for the main and lower levels. It should be noted that infiltration losses are second only to below grade losses in the level of uncertainity. This is why the data is calculated parametrically.

The following is a summary of the infiltration loss for a 24 hour period.

This is for the main level only. Entries are in BTUs/24 hr time period/ # days.

		AIR CHANGES/HOUR		
TIME PERIOD	# DAYS	0.2	0.3	0.4
Dec 1-7	7	456,969	685,455	913,938
Dec 8-14	7	369,507	554,263	739,015
Dec 15-21	7	600,713	901,070	1,201,427
Dec 22-31	10	865,515	1,298,773	1,731,030
Dec 1-31	31	2,250,924	3,376,387	4,501,848
Jan 1-7	7	304,491	456,737	608,983
Jan 8-14	7	407,606	611,409	815,212
Jan 15-21	7	517,007	775,510	1,034,013
Jan 22-31	10	450,056	675,084	900,112
Jan 1-31	31	1,709,633	2,564,450	3,419,267
Feb 1-7	7	372,925	559,387	745,850
Feb 8-14	7	317,233	475,849	634,466
Feb 15-21	4	183,156	274,735	366,313
Feb 22-29	8	401,223	601,834	802,446
Feb 1-29	26	1,264,484	1,896,726	2,528,968
Mar 1-7	7	316,389	474,585	632,778
Mar 8-14	7	282,932	424,398	565,864
Mar 15-21	2	75,341	113,011	150,682
Mar 22-31	9	386,227	579,341	772,454
Mar 1-31	25	1,038,799	1,558,199	2,077,598
Apl 1-7	7	260,866	391,300	521,732
Apl 8-13	6	240,632	360,949	481,265
Apl 1-13	13	502,957	754,436	1,005,914
HEATING SEASON AVERAGES/TOTALS				
Dec 1- Apl 13	126	6,643,957	9,965,939	13,287,915

The following is a summary of the infiltration loss for a 24 hour period. This is for the basement only. Entries are in BTUs/24 hr x # days/period.

		AIR CHANGES/HOUR		
TIME PERIOD	# DAYS	0.1	0.2	0.3
Dec 1-7	7	234,102	351,153	468,203
Dec 8-14	7	189,296	283,944	278,592
Dec 15-21	7	307,740	461,623	615,481
Dec 22-31	10	443,397	665,097	886,793
Dec 1-31	31	1,153,131	1,729,700	2,306,261
Jan 1-7	7	155,989	233,983	311,977
Jan 8-14	7	208,813	313,228	417,626
Jan 15-21	7	264,858	397,289	529,717
Jan22-31	10	230,560	345,841	461,120
Jan 1-31	31	875,831	1,313,751	1,751,664
Feb 1-7	7	191,046	286,570	382,093
Feb 8-14	7	162,516	243,775	325,032
Feb 15-21	4	93,830	140,744	187,659
Feb 22-29	26	205,543	301,538	411,087
Feb 1-29	26	647,735	971,680	1,295,570
Mar 1-7	7	162,084	243,126	324,167
Mar 8-14	7	144,944	217,416	289,888
Mar 15-21	2	38,597	57,895	77,193
Mar 22-31	9	197,861	296,792	395,722
Mar 1-31	25	532,169	798,255	1,064,337
Apl 1-7	7	133,640	200,460	267,279
Apl 8-13	6	123,274	184,916	246,548
Apl 1-13	13	257,661	386,492	515,322
HEATING SEASON AVERAGES/TOTALS				
Dec 1- Apl 13	126	3,375,678	5,063,517	6,751,356

6.3.4 SOLAR GAIN

6.3.4.1 General Discussion

The Montana Solar Data Manual, 1982 Edition was used as the source of solar energy available at the site. Dr. Charless W. Fowlkes, Fowlkes Engineering, Bozeman, Montana documented the solar energy available at various sites throughout Montana, supported by DNRC Grant funds, and documented his findings in the referenced manual. The ASHRAE CLEAR DAY TABLES for 48 Degrees North Latitude were used as the basis of available solar each month. 317 BTUH/sq ft = 1 KW/sq meter is the conversion factor. The collectors were South facing surfaces with a 90 degree angle to the horizon. A clearness factor of 1.05 for April through October and 1.08 for the rest of the year (refelection from snow in the winter) was used for the ASHRAE data by Dr. Fowlkes.

On a clear day it was assumed the data presented in the book was correct for Kalispell. Due to the proximity of Flathead Lake, it was assumed an additional 10% reduction due to the moisture in the air. On a clear day the energy specified by the clear day tables was used. On a partly cloudy day a reduction of 50% was applied. No useable solar energy was considered on cloudy days. In developing the useable heat from solar energy no long wave losses are considered during the calculations. The heat loss calculations take conduction losses into account.

On the following pages the amount of useable solar energy is developed.

6.3.4.2 Clear Day Data

Collector size = 70.37025 sq.ft.

TIME PERIOD	# DAYS	BTU/sq.ft	# CLEAR DAYS	# PARTLY CLOUDY	AVE KWH/M^2
Dec 1-7	7	1,304	1	0	1.4
Dec 8-14	7	1,304	0	1	1.4
Dec 15-21	7	1,304	2	1	1.4
Dec 22-31	10	1,304	4	3	1.4
Dec 1-31	31	1,304	7	5	1.4
Jan 1-7	7	1,478	2	0	2.0
Jan 8-14	7	1,478	2	0	2.0
Jan 15-21	7	1,478	0	1	2.0
Jan 22-31	10	1,478	3	1	2.0
Jan 1-31	31	1,478	7	2	2.0
Feb 1-7	7	1,720	3	2	2.6
Feb 8-14	7	1,720	0	1	2.6
Feb 15-21	4	1,720	0	0	2.6
Feb 22-29	8	1,720	2	0	2.6
Feb 1-29	26	1,720	5	3	2.6
Mar 1-7	7	1,632	3	2	3.8
Mar 8-14	7	1,632	1	0	3.8
Mar 15-17	2	1,632	0	0	3.8
Mar 23-31	9	1,632	2	2	3.8
Mar 1-31	25	1,632	6	4	3.8
Apl 1-7	7	1,262	2	2	4.4
Apl 8-13	6	1,262	1	3	4.4
Apl 1-13	13	1,262	3	5	4.4
HEATING SEASON TOTALS					
Ded 1-Apl 13	126	28	NA	19	NA

How to use this data: EG, The week of Dec. 1-7 had 7 days where one clear day and zero partly cloudy days occured. 1,304 BTU/sq of solar energy was available to the collector surface and 1.4 KW/sq meter generally, as the average Kalispell daily solar radiation. This is from recorded data & the reference manual.

Solar clear day data, continued.

The preceeding page indicated the number of clear days and the number of BTU/sq ft available to the collector. The next step is to determine the number of useable BTU/sq of collector size of delivered heat into the home. This is calculated as follows. The formula shown in section 6.2.6, solar gain, will be used.

MONTH	BTU/sq ft	Factor	Moist	Trans.	Absor.		BTU/sq ft of delivered heat
Dec.	1,304	x 1.08	x 0.9	x 0.75	x 0.85	=	808.0236 BTU/sq ft
Jan	1,478	x 1.08	x 0.9	x 0.75	x 0.85	=	915.8427
Feb.	1,720	x 1.08	x 0.9	x 0.75	x 0.85	=	1,065.798
Mar.	1,632	x 1.08	x 0.9	x 0.75	x0.85	=	1,011.2688
Apl.	1,262	x 1.05	x 0.9	x 0.75	x 0.85	=	760.2761

As a point of interest, the reason the solar energy does not increase dramatically as summer approaches, is the angle of the sun off the windows.

The next step is to multiply the BTU/sq ft by the collector size.

MONTH	BTU/sq ft/day	collector size	BTU/Day delivered heat
Dec.	808.0236	70.37025 sq ft	56,861
Jan.	915.8427	70.37025	64,448
Feb.	1,065.798	70.37025	75,000
Mar.	1,100.2688	70.37025	71,163
Apl.	760.2761	70.37025	53,501

6.3.4.3 PARTLY CLOUDY DAY DATA

The partly cloudy day data, presented below, is based on the average daily solar radiation measured from 1977 to 1982 in Kalispell,Montana. This is used as the best choice of the available choices. There is no accurate method to predict cloudy day solar radiation without measuring equipment.

BTUs available on a partly cloudy day is developed below.

MONTH	KWH/M^2	BTU/M^2	Inci. Fac	H_2O	Trans	Absor	Refra	BTU/sq ft/day
Dec.	1.4	x 316.8	x 0.90304	x 0.9	x 0.75	x 0.85	x 1.08	= 248.1799
Jan	2.0	x 316.8	x 0.86432	x 0.9	x 0.75	x 0.85	x1.08	= 339.3408
Feb	2.6	x 316.8	x 0.73819	x 0.9	x 0.75	x 0.85	x 1.08	= 376.7672
Mar.	3.8	x 316.8	x 0.5870	x 0.9	x 0.75	x 0.85	x 1.08	= 437.8782
Apl.	4.4	x 316.8	x 0.4102	x 0.9	x 0.75	x 0.85	x 1.05	= 344.4653

Combining the BTU/sq ft times the collector size for BTU/Day

MONTH	BTU/sq ft/DAY	COLLECTOR SIZE	BTU/DAY DELIVERED HEAT
Dec.	248.1799	70.37025 sq ft	17,464 BTU/DAY
Jan.	339.3408	70.37025	23,879
Feb	376.7672	70.37025	26,513
Mar.	437.8782	70.37025	30,814
Apl.	344.4653	70.37025	24,240

The next page will combine the delivered heat from the clear and partly cloudy days just presented to develop the total solar heat delivered.

6.3.4.4 SUMMARY: SOLAR GAIN

"A" = # clear days "B" = BTU/day "C" = BTU/Time Delivered "D" # partly cloudy days
"E" = BTU/day "F" = BTU/Time Delivered.

		CLEAR DAYS			PARTLY CLOUDY DAYS			TOTAL BTUs
TIME	days	A	B	C	D	E	F	DELIVERED
Dec 1-7	7	1	56,861	56,861	0	17,464	-0-	56,861
Dec 8-14	7	0	56,861	0	1	17,464	17,464	17,464
Dec 15-21	7	2	56,861	113,722	1	17,464	17,464	131,186
Dec 22-31	10	4	56,861	227,444	3	17,464	52,392	279,836
Dec 1-31	31	7	56,861	398,027	5	17,464	87,320	485,347
Jan 1-7	7	2	64,448	128,896	0	23,879	0	128,896
Jan 8-14	7	2	64,448	128,896	0	23,879	0	128,896
Jan 15-21	7	0	64,448	0	1	23,879	23,879	23,879
Jan22-31	10	3	64,448	193,344	1	23,879	23,879	217,223
Jan 1-31	31	7	64,448	451,136	2	23,879	47,758	498,894
Feb 1-7	7	3	75,000	225,000	2	26,513	53,026	278,026
Feb 8-14	7	0	75,000	0	1	26,513	26,513	26,513
Feb 15-21	4	0	75,000	0	0	26,513	0	0
Feb 22-29	8	2	75,000	150,000	0	26,513	0	150,000
Feb 1-29	26	5	75,000	375,000	3	26,513	79,539	454,539
Mar 1-7	7	3	71,163	213,489	2	30,814	61,628	275,117
Mar 8-14	7	1	71,163	71,163	0	30,814	0	71,163
Mar 15-17	2	0	71,163	0	0	30,814	0	0
Mar 23-31	9	2	71,163	142,326	2	30,814	61,628	203,954
Mar 1-31	25	6	71,163	426,978	4	30,814	123,256	550,234
Apl 1-7	7	2	53,501	107,002	3	24,240	48,480	155,482
Apl 8-13	6	1	53,501	53,501	3	24,240	72,720	126,221
Apl 1-13	13	3	53,501	160,503	5	24,240	121,200	281,703
SUMMARY: HEATING SEASON SOLAR HEAT DELIVERED								
Dec 1-Apl 13	126	28		1,811,644	19		459,073	2,270,717

2,270,717 BTUs of heat was delivered by solar energy during the monitoring.

6.3.5 INTERNAL GAIN

6.3.5.1 Internal Gain: People

The following assumptions are the basis of heat from people:

Each individual will average 50,000 calories each 10 hours and then increase to 85,000 calories for 14 hours as a function of activity levels. Internal gain is then calculated as follows:

50,000 cal./hr x 10 hour = 500,000 calories/person/day
with two people = 1,000,000 calories

85,000 cal./hr x 14 hour = 1,190,000 calories/person/day
with two people = 2,380,000 calories

Total calories each day = 3,380,000
Given: 1 BTU = 252 calories

2,380,000 cal. ÷ 252 BTU/cal = 13,412 BTUs

Summary

Daytime heat = 9,444 BTUs
Night time heat= 3,968 BTUs
Daily heat = 13,412 BTUs

6.3.5.2 Internal Gain: Electricity

General Discussion

A portion of the hot water is heated, or rather pre-heated from the wood furnace. The pre-heated water enters the electric hot water heater to bring it up to a constant faucet temperature of 120°F. The energy is apportioned between wood and electrical to determine how much internal gain is derived from electricity.

Delivery Rate- 8 tests were conducted per useage by filling a 5 gallon bucket and determining the rate as follows:

Shower 1 gallon/20 seconds = 3 gallon/minute
Bath tub 1 gallon/16 seconds = 3.75 GPM
Bath sink 1 gallon/28 seconds = 2.14 GPM
Kitchen sink 1 gallon/28 seconds = 2.14 GPM
Utility sink 1 gallon/28 seconds = 2.14 GPM
Dishwasher: per published specifications
Washingmachine: per published specifications

Daily consumption of hot water

2.34 showers @ 5 min ea = 12.15 min @ 3 GPM = 36.45 Gallon
Bath sink @ 1.5 minutes ave. = 1.5 min @ 2.14 GPM = 3.21 Gallon
Kit. sink @ 6 minutes ave. = 6 x 2.14 GPM = 12.84 Gallon
Dishwasher = 5 Gallon
Washing machine @ 7 gal/cycle x 3 cycle/day = 21 Gallon
Total Daily Consumption = 78.5 Gallons

The next page will indicate how much energy was provided by the wood and how much was provided by electricity each week to maintain the hot water utilized. This is calculated by the following formula:

BTUs required/day = 8.37 BTU/gal./°F x # days/time period x 78.5 Gal./day.

The temperature of the cold water, preheat tank and hot water tank were monitored and recorded each day.

Energy required to heat the hot water

	BTUs from wood			BTUs from electricity	
Time	#Day	Delta T	BTU Req'ed	Delta T	BTU Req'ed
Dec 1-7	7	58.857°F	270,702	15.143°F	69,647
Dec 8-14	7	56.857	261,503	17.143	78,846
Dec 15-21	7	59.857	275,301	14.143	65,048
Dec 22-31	10	56.7	372,545	17.3	113,669
Dec 1-31	31	58.067	1,180,050	15.933	327,210
Jan 1-7	7	45.428	208,938	28.572	131,411
Jan 8-14	7	50.285	231,277	23.715	109,072
Jan 15-21	7	59.857	275,301	14.143	65,048
Jan 22-31	10	43.5	285,815	30.5	200,399
Jan 1-31	31	49.767	1,001,331	24.233	505,930
Feb 1-7	7	37.142	170,828	36.855	169,522
Feb 8-14	7	38.285	176,084	35.715	164,265
Feb 15-21	4	37.5	98,557	36.5	95,929
Feb 22-29	8	41.375	217,482	32.628	171,489
Feb 1-29	26	38.575	662,951	35.425	601,205
Mar 1-7	7	43.428	199,739	30.572	140,610
Mar 8-14	7	39.0	179,373	35.0	160,976
Mar 15-17	2	39.5	51,907	34.5	45,336
Mar 23-31	9	39.33	232,574	34.67	205,018
Mar 1- 31	25	40.314	663,593	33.686	551,940
Apl 1-7	7	37.285	171,485	36.715	168,864
Apl 8-13	6	36.666	144,547	37.334	147,181
Apl 1-13	13	36.975	316,032	37.025	316,045
Total BTUs req!ed: WOOD			3,823,957	ELECT.	2,302,330

How to use this data: During the week of Dec 1-7, 78.5 gallons of water was heated each day by 58.857°F, requiring 270,702 BTUs from wood. The same 78.5 gallons of water was heated an additional 15.143°F and required 69,647 BTUs from the electricity to heat it to the 120°F faucet temperature.

Internal gain:electricity, continued.

From the preceeding page the following BTU/month is required for hot water:

Month BTU/Mo ÷ 3,413 BTU/KWH = KWH Consumption

Dec 327,210 = 94.872 KWH

Jan 505,930 = 148.236 KWH

Feb. 601,205 = 176.151 KWH

Mar. 551,940 = 161.717 KWH

Apl 316,045 = 92.600 KWH

Total electricity used for hot water = 674.576 KWH

674.576 KWH/126 days = 5.354 KHW/Day average

Electric Clothes Dryer

Average use each day was 40 minutes = 0.666 hours

5.5 KW rated strip heater x 0.666 hr = 3.666 KWH/Day

3.666 KWH/Day x 0.22 heat factor = 0.733 KWH/day as heat to home

0.733 KWH/day x 3,413 BTU/KWH = 2,503 BTU/day as home heat

Dryer summary

Daily electrical power consumption = 3.666 KWH

Internal Gains from dryer = 2,503 BTU/Day

Billed consumption from the power company

December = 1,260 KWH

Jan = 1,012 KWH

Feb = 1,050 KWH

Mar = 986 KWH

Apl 926 KWH x 43% (# days of test) = 401 KWH

Total billed electrical energy = 4,709 KWH ÷ 126 day = 37.37 KWH/day

SUMMARY OF ELECTRICAL POWER CONSUMPTION & INTERNAL HEAT GAINS

Average recorded consumption over the 126 day period.

USE	KWH/DAY	KWH/HEAT/DAY	BTU/HEAT/DAY
Clothes dryer	3.66	0.733	2,502
Hair dryer	0.147	0.147	503
Toster oven	0.147	0.147	502
Oven	0.921	0.921	3,143
Lights	1.503	0.451	1,539
Making coffee	0.245	0.245	836
Warming coffee	0.294	0.294	1,003
Breakfast	0.731	0.731	2,495
Lunch	0.0211	0.0211	72
Supper	6.186	6.186	21,113
Ironing	0.205	0.205	700
2 refrigerators	2.392	2.392	8,164
3 freezers	4.823	4.823	16,461
Washing machine	0.810	0.203	693
Hot water	5.354	5.354	18,273
Furnace fan	5.4629	5.4629	18,645
Television	2.813	1.125	3,840
Dishwasher	2.010	0.503	1,717
TOTALS	37.725 KWH/DAY		102,200 BTU/DAY

Recorded	37.725 KWH/DAY	An uncanny correlation.
Purchased	37.37 KWH/DAY	

6.3.6 SUMMARY: SOLAR PLUS INTERNAL GAIN

The entries below are in BTUs by category

TIME PERIOD	#DAYS	SOLAR	ELECTRICITY	PEOPLE	TOTAL
Dec 1-7	7	56,861	715,400	93,884	866,145
Dec 8-14	7	17,464	715,400	93,884	826,748
Dec 15-21	7	131,186	715,400	93,884	940,470
Dec 22-31	10	279,836	1,022,000	134,120	1,435,956
Dec 1-31	31	485,347	3,168,200	415,772	4,069,319
Jan 1-7	7	128,896	715,400	93,884	938,180
Jan 8-14	7	128,896	715,400	93,884	938,180
Jan 15-21	7	23,879	715,400	93,884	833,163
Jan 22-31	10	217,223	1,022,000	134,120	1,373,343
Jan 1-31	31	498,894	3,168,200	415,772	4,082,866
Feb 1-7	7	278,026	715,400	93,884	1,087,310
Feb 8-14	7	26,513	715,400	93,884	835,797
Feb 15-21	4	-0-	408,800	53,648	462,448
Feb 22-29	8	150,000	817,600	107,296	1,074,896
Feb 1-29	26	454,539	2,657,200	348,712	3,460,451
Mar 1-7	7	275,117	715,400	93,884	1,084,401
Mar 8-14	7	71,163	715,400	93,884	880,447
Mar 15-17	2	-0-	204,400	26,824	231,224
Mar 22-31	9	203,904	919,800	120,708	1,244,462
Mar 1-31	25	550,234	2,555,000	335,300	3,440,534
Apl 1-7	7	155,482	715,400	93,884	964,766
Apl 8-13	6	126,221	613,200	80,472	819,893
Apl 1-13	13	281,703	1,328,600	174,356	1,784,659
TOTALS					
Dec 1-Apl 13	126	2,270,717	12,877,200	1,689,912	16,837,829

How to use this form: For the week of Dec 1-7, 56,861 BTUs of heat was delivered into the home from solar energy, 715,400 BTUs from electricity and 93,884 BTUs from people for a total of 886,145 BTUs during the 7 days.

6.3.7 TOTAL SYSTEM EFFICIENCY

The overall efficiency of the Integrated Energy Production/Management System will be computed as follows:

Step No. 1 The sum of: (1) Conduction loss, plus (2) Basement infiltration loss @ 0.2 air changes/hr, plus (3) Main level infiltration loss @ 0.3 air changes/hr will be caluclated for each week/month/test period to determine the total number of BTUs of heat the building required.

Step No. 2 The sum of: (1) Solar gain, plus (2) Internal gain will be subtracted from the total number of BTUs required to heat the building, as defined in Step No. 1 above. The resultant figure is assumed to be the number of BTUs supplied by the wood heating system.

Step No. 3 The number of BTUs required to heat the home,as specified in step No 2 above, will be divided by the potential number of BTUs contained in the fuel burned, as specified in section 4.2, Fuel Analysis. The resulting number will be the overall efficiency of the Intergrated Energy Production/ Management System.

In addition to this presented method,as previously mentioned, Mr. Michael Chapman, Program Engineer, Energy Division, DNRC, utilized the Mitalas model for below grade heat loss. This is contained in the appendix of this report. The basic difference between the two calculations is the amount of heat assumed for below grade, concrete conduction loss. In the Mitalas model less heat is assumed to be lost, resulting in a slightly lower overall efficiency.

The overall loss, as calculated by the contractor, is summarized in the next few pages. The fixed below grade heat loss calculation indicates an overall efficiency of 87% while the Mitalas Model yields 73.5%.

Total System Efficiency, continued "TOTAL BUILDING LOSSES"
Entries are in BTUs

Time	# Day	Cond. Loss	Infil.Bsm't	Infil.Main	Total Loss
Dec 1-7	7	5,864,095	351,153	685,455	6,900,703
Dec 8-14	7	4,966,079	283,944	554,263	5,804,286
Dec 15-21	7	7,339,997	461,623	901,070	8,702,690
Dec 22-31	10	10,561,213	665,097	1,298,773	12,525,083
Dec 1-31	31	28,302,397	1,729,700	3,376,387	33,408,484
Jan 1-7	7	4,298,523	223,983	456,737	4,989,243
Jan 8-14	7	5,357,256	313,228	611,409	6,281,893
Jan 15-21	7	6,480,535	397,289	775,510	7,653,334
Jan 22-31	10	6,295,460	345,841	675,084	7,316,385
Jan 1-31	31	22,744,668	1,313,751	2,564,450	26,672,869
Feb 1-7	7	5,001,168	286,570	559,387	5,847,125
Feb 8-14	7	4,431,286	243,775	475,849	5,150,910
Feb 15-21	4	2,550,365	140,744	274,735	2,965,844
Feb 22-29	8	5,459,170	301,538	601,834	6,364,542
Feb 1-29	26	17,336,826	971,680	1,896,726	20,205,232
Mar 1-7	7	4,420,685	243,126	474,585	5,138,396
Mar 8-14	7	4,077,159	217,416	434,398	4,728,973
Mar 15-17	2	1,108,464	57,895	113,011	1,279,370
Mar 22-31	9	5,472,647	296,792	579,341	6,348,780
Mar 1-31	25	14,852,145	798,255	1,558,199	17,208,599
Apl 1-7	7	3,850,596	200,460	391,300	4,442,356
Apl 8-13	6	3,475,400	184,916	360,949	4,021,265
Apl 1-13	13	7,340,973	386,492	754,436	8,481,901
SEASON TOTALS					
Dec 1-Apl 13	126	88,806,380	5,063,517	9,965,939	103,835,831

HOW TO USE THIS DATA CHART: During the 7 days of Dec. 1-7, the building lost 5,864,095 BTUs through conduction loss, 351,153 BTUs through air changes in the basement and 685,455 BTUs main level infiltration loss for a total loss of 6,900,703 BTUs. This is how much heat the building required each period.

TOTAL SYSTEM EFFICIENCY

Entries in BTUs TIME	# DAY	TOTAL LOSSES	SOLAR + INTERNAL GAINS	BTUs FROM FUEL	POTENTIAL BTUs FROM WOOD	OVERALL SYSTEM EFFICIENCY	
Dec 1-7	7	6,900,703	886,145	6,034,558	6,541,668	92.248%	
Dec 8-14	7	5,804,286	826,748	4,977,538	5,507,082	90.384%	
Dec 15-21	7	8,702,690	940,470	7,762,220	8,578,710	90.482%	
Dec 22-31	10	12,525,083	1,435,956	11,089,127	12,684,924	87.419%	
Dec 1-31	31	33,408,484	4,069,313	29,339,165	33,312,384	88.072%	
Jan 1-7	7	4,989,243	938,180	4,051,063	4,594,590	88.170%	
Jan 8-14	7	6,281,893	938,180	5,343,713	6,207,516	86.084%	
Jan 15-21	4	7,653,334	833,163	6,820,171	7,666,218	88.96%	
Jan 22-29	10	7,313,385	1,373,343	5,943,042	7,467,012	79.59%	
Jan 1-31	31	26,622,869	4,082,866	22,540,003	25,935,336	86.908%	
Feb 1-7	7	5,847,125	1,087,310	4,759,815	5,532,064	85.730%	
Feb 8-14	7	5,150,910	835,797	4,315,113	4,710,258	91.610%	
Feb 15-21	4	2,965,884	462,448	2,503,396	2,859,576	87.544%	
Feb 22-29	8	6,362,542	1,074,896	5,287,646	6,059,718	87.258%	
Feb 1-29	26	20,205,232	3,460,451	16,774,781	19,181,610	87.296%	
Mar 1-7	7	5,138,396	1,084,401	4,053,995	4,517,478	89.974%	
Mar 8-14	7	4,728,973	880,447	3,848,576	3,951,990	97.381%	*
Mar 15-17	2	1,279,370	231,224	1,048,146	873,936	119.933%	*
Mar 22-31	9	6,348,780	1,244,462	5,104,318	5,108,670	99.914%	*
Mar 1-31	25	17,208,599	3,440,534	13,768,065	14,452,074	95.267%	*
Apl 1-7	7	4,442,356	964,766	3,477,590	3,851,304	89.598%	
Apl 8-13	6	4,021,265	819,893	3,201,372	2,975,238	107.600%	*
Apl 1-13	13	8,481,901	1,784,659	6,697,242	6,856,542	97.676%	*

* These efficiencies are obviously inaccurate. Neither DNRC nor the contractor can find out why. The best possibility is the effects of non-fuel gain estimates during the period, i.e., solar. The numbers as listed are included in the following overall system efficiency. If excluded, the efficiency would be lower and approaching that of the efficiencies of the fireplace insert which uses identical technology.

SUMMARY: OVERALL TOTALS OF SYSTEM EFFICIENCY

Dec 1-Apl 13	126	103,835,836	16,837,829	86,998,007	99,737,946	87.226%

NOTE: The average of Dec. , Jan & Feb. (high confidence data) is 87.425%

6.4 FIREPLACE INSERT DATA REDUCTION & RESULTS

6.4.1 General Discussion

The fireplace insert was designed with the concept that secondary combustion would take place in the afterburner chamber. During the initial testing it was determined no significant combustion occurs in the afterburner chamber. A mirror was placed under the chamber to permit observation. No flames were observed during several tests.

Several tests were conducted prior to the recording of the data to verify this observation. Oxygen was cut off from the afterburner and test conditions duplicated the essentially identical results. Test # 1 & 2 are reported in the following summary. They were one day apart with identical amounts of fuel. The overall efficiency in an afterburner mode (oxygen to afterburner) was 89.03%. 88.85% efficiency was measured when the oxygen was shut off.

This unexpected finding is extremely good as the only variable automatically becomes the control of combustion oxygen. This greatly simplifies the design.

You are referred to the monitoring plan discussed in Section 4 for the methodology utilized. The data collected is listed in section 5.2, Fireplace Insert.. Section 6, Data Analysis shows the specific calculations and formulas used. Section 6.2.3 specifies how the radiant heat was calculated while section 6.2.4 shows the calculation of convection heat.

The wood used was tested and came from the same stack as that just discussed in the Integrated Energy Production/Management System.

No extensive narrative is necessary for the monitoring of the fireplace insert. One single test was done during an entire day. The test would begin by starting the fire with newspaper and kindling. Usually an 8 pound load of fuel was used to get the fire going. Starting from a cold insert, a 15 to 20 minute time period was required to reach initial operating temperatures. Depending on the type of test to be run that day, 15 to 20 pounds of fuel was loaded and the cast iron doors sealed. The lever was pulled to seal off the top of the unit and the test would begin.

A discussion about the various type tests conducted and why follows. The fireplace insert is basically a sealed, six sided firebox with an opening in the rear,lower level for the products of combustion to escape to the chimney. The coals must not be disturbed by the flow of air or they will cool below the point requisite to sustain operational temperatures the design dictates for such high efficiency. This is achieved by a "nest" of ashes around the coals. To verify such a simple technique works, a total of 13 tests were conducted in what is called the "Basic Mode, Ash Base". Conversely, to show what happens when the design parameters are changed, several tests were conducted by raising the bed of coals off its designed ash nest by placing the fire on a conventional fireplace grating and raising the level of the coals. This allowed the flow of air and gases around the coals and the resultant cooling effects on combustion.

Another test was an excess oxygen test. More outside air was allowed into the insert than the design specified. The fire burned vigorously, however the flow of air cooled the coals excessively due to the venturi action of the design. Another test was the minumum fuel test. There was insufficient fuel to maintain operational temperatures.

6.4.2 TEST RESULTS

Each time a test was run, it was analyzed to determine what the next test should be. Samples of the actual raw data are shown in the appendix. Due to the simplicity of the calculations, the results were entered on the data sheet and the underlying calculations not recorded. The summary of the results of each test are presented.

TEST #	TEST DATE	TYPE OF TEST	LB WOOD	% OF TOTAL AS RADIANT HEAT	OVERALL EFFICIENCY
1	1/18/84	Afterburner in ash base	37 lb	11.27%	89.03%
2	1/19/84	Basic mode, ash base	37 lb	10.98%	88.85%
3	1/20/84	Basic mode, no ash base	37 lb	7.12%	67.62%
4	1/23/84	Basic mode, ash base	60 lb	11.60%	82.38%
5	1/28/84	Basic mode, ash base	75 lb	6.17%	88.13%
6	2/3/84	Basic mode, ash base	52 lb	12.05%	88.26%
7	2/7/84	Basic mode, ash base	55 lb	11.78%	89.24%
8	2/11/84	Basic mode, ash base	58 lb	12.01	88.77%
9	2/14/84	Basic mode, ash base	45 lb	11.23%	91.09%
10	2/20/84	Basic mode, ash base	66 lb	10.78%	86.79%
11	2/24/84	Basic mode, ash base	84 lb	9.99%	88.33%
12	2/29/84	Basic mode, ash base	77 lb	11.03%	90.27%
13	3/1/84	Basic mode, ash base	91 lb	12.79%	89.56%
14	3/4/84	Basic mode, ash base,Max fuel	104lb	14.82%	87.70%
15	3/9/84	Basic mode,ash base,Min fuel	20 lb	8.2%	66.04%
16	3/13/84	Basic mode, ash base,Excess O_2	36 lb	12.8%	73.28%
17	3/16/84	Basic mode, ash base Unheated excess O_2 & Min fuel	24 lb	14.24%	57.96%
18	3/25/84	Coals raised 2 inches	43 lb	9.51%	71.7%
19	3/29/84	Coals raised 3½ in,Min fuel	20 lb	8.23%	37.9%
20	4/2/84	Coals raised 3½ in,Min fuel	20 lb	7.3%	52.61%
21	4/5/84	Coals raised 3½ in,Min fuel	37 lb	7.76%	65.08%

Overall efficiency was calculated by dividing the sum of the delivered heat from the radiant and convection energy by the potential heat contained in the fuel burned.

SECTION 7 ECONOMIC ANALYSIS

General Discussion

The costs shown are for delivering the same amount of heat energy into the building for different types of heating systems. This assumes only the source of heat is changed. It must be emphasized that the very low requirement for heat is a direct function of the "Total System Design" thinking used in the design, not the fact a renewable energy source was used. This does not mean the wood furnace, by itself, is all that is required. It is the total system design, which incorporates the source of heat that is practical and cost-effective for the site, that produces such a low heat requirement. If the wood furnace were placed in the same 3,600 square foot home without the total system approach, a very dramatic increase in fuel would result.

7.1 Annual fuel cost for various energy sources for comparison

WOOD

5.32 cords of wood were required for this heating season. 86,998,007 BTUs of heat were delivered into the home.

5.325 Cords @ $50/cord, the cost of wood was:	$266

ELECTRICITY

86,998,007 BTUs delivered ÷ 3,413 BTU/KWH = 25,490 KWH required.

At 5.9¢/KWH, the cost of electric heating would be:	$1,504

HEATING OIL

86,998,007 BTUs delivered ÷ 142,359.45 BTU/Gal. @ 95% effic.

611 gallons would be required.

At $1.04/Gal, the cost of heating oil would be:	$635

NATURAL GAS

86,998,007 BTUs delivered ÷ 950,000 BTU/MCF @ 95% effic.

92 MCF of gas would be required

At $4.481/MCF the cost of natural gas would be:	$412

SUMMARY OF FUEL COSTS

All costs are in 1984 dollars

Wood	$266
Electricity	$1,504
Heating Oil	$635
Natural Gas	$412

7.2 Capital System Acquisition Costs

				FURNACE containing				
TYPE SYSTEM	AIR DIST	AIR RET'rn	OIL TANK	AIR BLOWER	AIR FILTER	SYSTEM CONTROL	BACKUP CHIM.SYSTEM	INITIAL COST
WOOD	$1,000	$300		$700		$100	$1,000 $500	$3,600
ELECT.	$1,000	$300		$800		$100		$2,200
OIL	$1,000	$300	$500	$1,200		$100	$1,000	$4,100
Gas	$1,000	$300		$1,200		$100	$1,000	$3,600

7.3 LIFE CYCLE COSTS

7.3.1 ANNUAL AND CUMULATIVE COSTS COMPARISON

This chart shows the annual and cumulative costs required to buy the fuel assuming a 5% annual inflation rate.

	WOOD		ELECTRICITY		OIL		GAS	
Yr	ann.	Cum.	ann.	Cum.	Ann.	Cum.	Ann.	Cum.
1	$266	$266	$1,504	$1,504	$635	$635	$412	$412
2	$279	$545	$1,579	$3,083	$667	$1,302	$433	$845
3	$293	$838	$1,658	$4,741	$700	$2,002	$454	$1,299
4	$308	$1,146	$1,741	$6,482	$735	$2,737	$477	$1,776
5	$323	$1,469	$1,828	$8,310	$772	$3,509	$501	$2,277
6	$339	$1,808	$1,920	$10,230	$810	$4,319	$526	$2,803
7	$356	$2,164	$2,016	$12,246	$851	$5,170	$552	$3,355
8	$374	$2,538	$2,116	$14,362	$894	$6,064	$580	$3,935
9	$393	$2,931	$2,222	$16,584	$938	$7,002	$609	$4,544
10	$412	$3,343	$2,333	$18,917	$985	$7,987	$639	$5,183
11	$433	$3,776	$2,450	$21,367	$1,034	$9,021	$671	$5,854
12	$455	$4,231	$2,572	$23,939	$1,086	$10,107	$705	$6,559
13	$478	$4,707	$2,701	$26,640	$1,140	$11,247	$740	$7,299
14	$502	$5,211	$2,836	$29,476	$1,197	$12,444	$777	$8,076
15	$527	$5,738	$2,978	$32,454	$1,257	$13,701	$816	$8,892

How to use this chart. Wood that costs $266 the first year will cost $527 in the 15th year at an annual inflation rate of 5%. After 15 years a total of $5,738 would have been spent on the wood fuel.

7.3.2 LIFE CYCLE AND PAY BACK COST COMPARISON

	TOTAL SYSTEM COSTS TO OWNER Cumulative fuel + capital initial $				DIFFERENTIAL SAVINGS TO OWNER i.e., the $ saved by using the wood system compared to the use of these:		
Yr	WOOD	ELECT	OIL	GAS	ELECT	OIL	GAS
1	$3,866	$3,704	$4,735	$4,012	- $182	$849	$126
2	$4,145	$5,283	$5,402	$4,445	$1,138	$1,257	$300
3	$4,438	$6,941	$6,102	$4,899	$2,503	$1,664	$461
4	$4,746	$8,682	$6,837	$5,376	$3,936	$2,091	$630
5	$5,069	$10,510	$7,609	$5,877	$5,441	$2,540	$808
6	$5,406	$12,430	$8,419	$6,403	$7,024	$3,013	$997
7	$5,764	$14,446	$9,270	$6,955	$8,682	$3,506	$1,191
8	$6,138	$16,562	$10,164	$7,535	$10,031	$4,026	$1,397
9	$6,531	$18,784	$11,102	$8,144	$12,253	$4,571	$1,613
10	$6,943	$21,117	$12,087	$8,783	$14,624	$5,144	$1,840
11	$7,376	$23,567	$13,121	$9,454	$16,200	$5,745	$2,078
12	$7,831	$26,139	$14,201	$10,159	$18,308	$6,370	$2,328
13	$8,309	$28,840	$15,347	$10,899	$20,531	$7,038	$2,590
14	$8,811	$31,676	$16,544	$11,676	$22,865	$7,733	$2,866
15	$9,338	$34,654	$17,801	$12,492	$25,316	$8,463	$3,154

HOW TO USE THIS DUAL SET OF DATA:
The TOTAL SYSTEM COSTS, on the left, combines the cost to initially buy the system with the annual fuel costs that are increasing at 5% each year. For example, in the first year it would have cost $3,600 to install the wood system, puls an additional $266 for the wood. After 15 years, the owner would have spent $9,338 for the system and the 15 years of fuel to heat the home.

The right hand columns of data, entitled DIFFERENTIAL SAVINGS TO OWNER, indicates the total savings possible if a wood system is used instead of the other types indicated. For example, if electricity was used, instead of the wood system, the first year would cost $182 more using wood. However, by the end of the second year a net overall savings of $1,138 would accrue. Over a 15 year period $25,316 would be saved by not using electricity.

Summary: After approximately 2 years pay back time, it is cheaper to use the renewable wood system, compared to the other energy sources. After the two year period, you heat the home and do it for significantly less than any of the other fuels considered.

SECTION 8. RECOMMENDATIONS AND CONCLUSIONS

8.1 Comparison of Design vs Actual Performance

8.1.1 Integrated Energy Production/Management System

This system is the result of at least 15 years of design, research, development, construction, testing, review and building on the tests and lessons learned. As such there were no surprises, per se. Looking back on the efficiencies during the warmer spring testing, it points out that energy reality still holds a great deal of art when you desire it to be a pure science. It was most gratifying that the overall efficiency of the system during the three months of extremely cold weather averaged very close to that of the fireplace insert, which is essentially an identical design applied to a different specific application.

Each of the previous system designs during the preceeding 15 years came within a few percentage points of the design expectations. This system duplicated the design calculations.

8.1.2 Fireplace Insert

The major surprise was the fact the insert did not function in the afterburner for the secondary combustion. The combustion, both primary and secondary, occurs in the primary combustion chamber. The efficiency of the overall unit essentially verified the design calculations.

8.2 Materials Analysis

Integrated Energy Production/Management System

Without exception, all materials used are standard, off the shelf, commerciallly available components. Anyone desiring to duplicate the system or apply it to comparable circumstances should not have any problem obtaining the materials to do so.

Fireplace Insert

This was a custom fabrication from an orgional design. I could easily tell a "capable" individual what to do and what not to do so as to easily duplicate the unit and the results. The key design components are such that commercialization and mass production of the insert would pose no problems. However, no one should endeavor to duplicate the unit without being advised. The insert develops such intense energy levels that it has a potential fire danger if fail safe features and a proper means of removing heat as it is generated are not incorporated.

8.3 IMPROVEMENTS

Integrated Energy Production Management System

After several years in operation, there are only two very minor improvements recommended. First, deals with the hot water pre-heat system. Not knowing how well a design would function, many additional valves, controls etc. were installed. Most of the plumbing shown in the photograph is not required. On the next house (currently being designed) the system will be greatly simplified.

The second improvement is a fail-safe shut down when the electricity goes off. Currently, a bimetalic sensor maintains a very small amount of oxygen to the sealed firebox to keep the fire from going out. During prolonged periods of power outage the heat generated will slowly accumulate if nothing is done. It has been no real problem, as a manual turn off reduces all oxygen. It would be desirable to have an automatic shut off of the bimetalic oxygen control when the power is off.

Fireplace Insert

The fireplace insert is essentially an engineering model. It has clearly demonstrated that it works. Improvements lie in the realm of practical commericalization. There are no true fundamental improvements necessary at this stage.

8.4 APPLICATIONS TO VARIOUS AREAS OF MONTANA

Integrated Energy Production/Management System

This system is immediately and directly applicable to all applications in Montana. The system technology has been demonstrate for the past 15 years by the contractor, R.G. Wrench, in the series of homes and energy systems designed, constructed and tested. This activity had demonstrated there is absolutely no problem, what so ever, in designing a renewable energy system into a home, new or retrofit, that can duplicate the results reported herein. The only variable is what renewable energy is most cost-effective. For example, here in Kalispell, the winters have very little sun and the land produces low cost cord wood. That is the only reason the wood system was selected. If this home was being built in the sun belt of eastern Montana the renewable energy source would have been solar.

Fireplace Insert

The technology is directly applicable to anyone that has a fireplace. The next step, if this is to be applied to the benefit of Montana's citizens, must be the commericalization of the technology. When the basic hardware is compared to what is now available, it is quite apparent this fireplace insert technology could be made available at the comparable cost of any insert now on the market. The design is really quite simple.

8.5 Economic Performance

Section 7, Economic Analysis, clearly shows the renewable energy system will save money after the initial payback period. In this specific case, the pay back period was less than two years. For other applications the time may vary, however, it is definitely cheaper to use the renewable energy system, depicted in this home, along with the total system approach to energy management. This combined approach allows the home to be heated for a very small amount of money when compared to conventional designs in both homes and heating systems.

In the case of the fireplace insert, only subjective opinion is possible. If wood can be converted into delivered heat at the 85-90% efficiency range, it is only logical that the unit must have an economic and viable potential for good performance.

8.6 GENERAL COMMENTS AND RECOMMENDATIONS

This technology should be made available to the citizens of Montana, in a practical manner today, so they can heat their homes for a low cost.

APPENDIX No. 1

COPIES OF THE HANDWRITTEN RAW DATA
FOR THE
INTEGRATED ENERGY PRODUCTION/MANAGEMENT
SYSTEM.

[illegible]
MANAGEMENT SYSTEMS

DECEMBER

TYPE DAY	OUTSIDE AIR TEMPERATURE in °F							AVE WATER TEMP IN PRE-HEAT in °F	WEIGHT OF WOOD BURNED & TIME LOADED		12 HOUR DAY TIME TOTALS			12 HOUR NIGHT TIME TOTALS		
C = CLEAR O = OVERCAST W = WIND	OVER NIGHT LOW	8 AM	12 NOON	4 PM	8 PM	DAY ① TIME AVE	② NIGHT TIME AVE		PRIOR NIGHTS CONSUMPTION	CONSUMPTION DURING THE DAYTIME	ΔT IN/OUT	③ LBS BURN	④ BTU/H CONSTANT OUTPUT	ΔT IN/OUT	⑤ LBS BURNED	⑥ BTU/H CONSTANT OUTPUT
O	-6	-5	+10	+10	0	+3.75	+2	98	61@8A	59@12N, 58@8PM	66.25	117	56,155	60	61	29,382
O	-4	+10	+21	+15	+16	+15.5	+2	102	63@8A	57@1PM, 48@8PM	54.15	105	50,575	60	63	30,345
O	+12	+16	+24	+21	+10	+17.75	+14.66	105	48@8A	45@2PM, 47@8PM	52.25	92	44,313	47.34	48	23,120
O	+10	+10	+21	+20	+16	+16.75	+10	104	58@8A	53@1PM, 37@8PM	53.25	90	43,350	52	58	27,345
O	+8	+12	+27	+20	+18	+19.25	+12	105	63@8A	43@3PM, 27@8PM	50.75	70	33,715	56	63	30,345
O	+8	+12	+25	+19	+14	+17.5	+12.66	105	47@8A	50@2PM, 37@8PM	52.5	87	41,905	49.34	47	22,638
W/C	+4	+6	+22	+18	+18	+16	+8	115	58@8A	38@3PM, 21@8PM	56	59	28,418	54	58	27,937
O	+7	+10	+25	+24	+20	+19.75	+11.66	103	63@8A	51@12N, 48@8PM	50.25	99	47,685	52.34	63	30,345
O	+15	+20	+32	+31	+32	+28.75	+18.35	105	38@8A	42@2PM, 34@8PM	43.25	76	36,606	43.66	38	18,303
O	+30	+32	+38	+34	+30	+33.5	+31.33	106	42@8A	38@3PM, 23@8PM	38.5	61	29,382	30.66	42	20,230
P/C	+21	+25	+33	+30	+29	+29.25	+26.5	102	53@8A	25@2PM, 39@8PM	42.75	64	30,827	36.6	53	25,528
O	+21	+22	+31	+30	+20	+23.25	+24	104	40@8A	48@3PM, 12@8PM	48.75	60	28,900	38	40	19,267
O	+17	+20	+37	+29	+23	+27.5	+15.33	95	51@8A	40@2PM, 55@8PM	48.5	95	45,758	46.67	51	24,565
O	+10	+13	+28	+26	+23	+22.5	+16.33	102	40@8A	42@2PM, 33@8PM	49.5	75	36,125	45.67	40	19,267
P/C	+13	+15	+50	+24	+21	+22.5	+14.33	100	40@8A	38@3PM, 33@8PM	49.5	71	34,198	46.67	40	19,267
[illegible]	+10	+12	+8	+2	0	+5.5	-15.33	100	39@8A	52@2PM, 40@3:30, 60@8PM	66.5	152	73,213	77.33	39	18,785
C	-24	-22	-15	0	-8	-11.25	-7.66	125	75@8A	40@11, 31@4, 46@8	79.66	117	56,355	69.66	75	36,125
W/O	-15	0	+13	+5	-5	+3.25	-9.0	106	90@8A	72@1PM, 65@7PM	68.75	112	53,947	71	90	43,350
W/O	-16	-6	+7	+4	0	0	-7.33	103	65@8A	45@12N, 47@5:30, 45@8	72	137	65,988	69.33	65	31,308
W/O	-14	-8	0	-4	-8	-5	-17.33	104	63@8A	72@1PM, 37@4, 24@7, 31@8	75	174	83,810	77.3	63	30,345
C	-24	-22	-10	-9	-20	-15.25	-22.66	107	74@8A	24@10, 24@12, 24@4, 54@8	67.25	126	60,690	84.66	74	35,643
C	-26	-22	-20	-15	-21	-19.5	-24	105	115@8A	48@11, 24@5, 55@8PM	91.5	127	61,172	86	115	55,392
C	-27	-24	-20	-10	-18	-18	-27.33	101	102@8A	35@12, 31@5, 54@8PM	90	120	57,800	89.33	102	49,130
C	-34	-30	-18	-11	-16	-18.75	-26.33	124	100@8A	56@1, 30@5, 41@8PM	90.75	127	61,172	78.33	100	48,166
C	-21	-12	-8	0	0	-5	-3.66	110	92@8A	37@2PM, 45@8PM	72	82	39,497	65.66	92	44,313
O	-8	+2	+11	+9	+5	+6	+6.75	96	66@8A	41@1, 49@8	65.25	90	43,350	56	66	29,245
W P/C	+5	+5	+10	+9	-6	+5.25	-16.33	95	60@8A	33@1, 27@4, 42@5	66.75	100	48,167	76.33	60	28,900
P/C	-25	-18	+9	-4	-14	-6.75	-18.66	100	69@8A	47@12, 50@5, 41@8	78.75	138	66,470	86.66	69	33,235
P/C	-27	-15	+9	+5	0	-0.25	+2.33	98	92@8A	58@2, 33@3, 41@8	71.75	149	67,733	57.66	92	44,313
O	0	+7	+15	+10	+8	+10.75	+6.66	95	67@8A	33@1, 26@4, 34@8	61.25	93	44,795	54.4	88	32,372
O	+4	+5	+18	+22	+20	+17	+17.33	97	42@8A	54@1, 68@8	55	122	58,763	44.67	42	20,230

① DAYTIME AVE = 8AM + 12N + 4PM + 8PM ÷ 4; ② NIGHTTIME AVE = 8PM + LOW + 8AM, ÷ 3

③ DAYTIME CONSUMPTION = SUM OF DAY'S LOADS + 8PM, BUT NOT 8AM LOADING; ④ & ⑥ = ③ or ⑤ × 5,780 BTU/LB ÷ 12HR

⑤ NIGHTTIME CONSUMPTION = # LBS LOADED @ 8AM = WEIGHT BURNED DURING THE 12HR NIGHT

3,187 LB day + 2,005 LB night = 5,192 LB = 1.674 CORD BY WEIGHT

1.7349 CORD BY [illegible]

RENEWABLE ENERGY
MANAGEMENT SYSTEMS

JANUARY

TYPE DAY	OUTSIDE AIR TEMPERATURE IN °F							AVE PRE HEAT WATER TEMP IN °F	WEIGHT OF WOOD BURNED IN POUNDS		DAY TIME TOTALS			NIGHT TIME TOTALS		
	OVER NIGHT LOW	8 AM	12 NOON	4 PM	8 PM	DAY ① TIME AVE	② NIGHT TIME AVE		TIME & WEIGHT LOADED PRIOR NITE'S CONSUMPTION	DAY TIME CONSUMPTION	ΔT FROM TO OUTSIDE	③ LB BURN	④ BTUH @ [illegible] E	ΔT H2O TO ATTIC	⑤ LB BURN	⑥ BTUH @ [illegible] E
O	+12	+25	+31	+25	+16	+23	+17.33	94	41@6	31@1 44@8	49	75	36,125	44.67	41	19,748
O	+9	+20	+33	+29	+26	+27	+27.33	89	48	37@1 31@8	45	68	32,753	34.67	48	23,120
O	+26	+30	+33	+31	+30	+31	+29.66	92	53	35@2 24@8	41	62	29,863	32.34	53	25,525
O	+25	+31	+39	+41	+40	37.75	+38	92	35	42@2 33@9	34.25	75	36,125	24	35	16,858
C	+34	+40	+43	+40	+38	40.25	+31.66	95	33	16@3 22@8	31.75	38	18,303	30.34	33	15,875
O	+27	+30	+36	+37	32	33.75	30	85	46	37@3 14@9	38.25	53	25,528	32	46	22,157
C	+28	+30	+35	+39	+35	34.75	31.33	93	46	21@1, 20@9	37.25	42	20,230	30.67	46	22,157
O	+27	+32	+37	+32	+30	32.75	+21	97	46	36@1 37@8	39.25	73	35,162	41	46	22,157
C	+16	+17	+32	+24	+20	23.25	+19.66	87	44	35@2 34@8	48.75	72	34,680	42.34	44	21,193
O	+17	+22	+29	+29	+28	27	+25	86	38	49@2 34@8	45	83	39,978	37	38	18,303
O	+20	+25	+33	+29	+30	30	+27	92	49	30@3 33@8	42	63	30,345	35	49	23,602
O	+24	+27	+32	+28	+20	+26.75	+13.33	87	45	41@4 28@8	45.25	79	38,052	48.67	45	21,675
O [illegible]	+8	+12	+23	+15	+5	+13.75	0	105	53	42@2, 57@6, 37@9	58.25	136	65,507	62	53	25,528
[illegible]	-5	0 [illegible]	+10	+12	+3	+6.25	-4	120	89	45@2 51@8	65.75	96	46,240	66	89	42,868
O	-10	-5	+8	+10	+12	+6.25	+6	104	85	32@12 57@8	65.75	91	43,832	56	85	40,942
O [illegible]	0	+6	+15	+10	+5	9	-4	112	55	51@12 50@5 39@8	63	140	67,433	70	58	27,937
C	-18	-14	+2	+4	-6	-3.5	-4.66	97	78	36@1, 26@3 50@8	75.5	112	53,945	64.66	78	37,570
PC	-5	0	+11	+10	+4	+6.25	+2.66	125	66	42@12, 10@4 58@9	65.25	110	52,983	51.34	66	31,790
C	0	+4	+17	+11	+9	+10.25	+5.33	110	74	35@12 38@8	61.75	73	35,162	56.67	74	35,643
O	+2	+5	+14	+12	+12	+10.75	+11	98	63	52@2 60@8	61.25	112	53,947	51	63	30,345
O	+9	+12	+12	+14	+15	+13.25	+14.66	75	49	46@3 36@8	58.75	82	39,497	47.34	49	23,602
O	+13	+16	+27	+31	+28	+26	+27.33	80	25	58@1 50@8	46	108	52,020	34.67	25	12,042
O	+25	+29	+35	+32	+30	+31.5	+28.33	97	50	31@3 48@9	40.5	79	38,052	33.67	50	24,083
O	+26	+29	+35	+34	+31	32.25	31	75	52	~~35~~ 46@3 23@9	34.75	69	33,235	30	52	[illegible]
PC	+28	+34	+41	+40	35	+37.5	+~~30.33~~	87	49	56@7	34.5	56	26,973	32	49	23,965
O	+26	+29	+35	+34	+32	+32.5	33	89	52	47@3 23@9	39.5	70	33,717	29	52	25,047
O	+32	+35	+35	+40	+35	+37	+35	89	51	35@4 23@8	35	58	27,937	27	51	24,565
O	+33	+35	+40	+40	+37	+38	+33	72	53	76@4 ~~37~~ 20@8	34	66	31,790	29	53	25,528
C	+30	+32	+35	+32	+30	+33	+23.66	90	40	49@4 — 9@8	39	58	27,937	35.34	40	19,267
C	+18	+20	+32	+32	+22	+26.5	14.33	87	41	58@8 —	45.5	58	27,937	47.67	41	19,748
C	-9	+12	+34	+32	+20	+24.5	+19	84	49	62@4 18@8	47.5	80	38,533	43	49	23,602
												2,357			1,599	

3956 lb burned = 1.27 cord by weight,
vol ~~[illegible]~~ 1.365 cord burned

FEBRUARY

R[illegible]ble E[illegible]gy MANAGEMENT SYSTEMS

THE DAY	OUTSIDE AIR TEMPERATURE °F OVER NIGHT LOW	8 AM	12 NOON	4 PM	8 PM	① DAY TIME AVE	② NIGHT TIME AVE	AVE PRE HEAT WATER TEMP	WEIGHT OF WOOD BURNED IN POUNDS — TIME & WEIGHT LOADED PRIOR NIGHT'S CONSUMPTION	DAYTIME CONSUMPTION	DAY TIME TOTALS ΔT 70 IN TO OUTSIDE	③ LB BURN	④ BTUH 60% E	NIGHT TIME TOTALS ΔT 62 TO OUTSIDE	⑤ LB BURN	⑥ BTUH 60% E
PC	+17	+20	+30	+33	+27	+27.5	+18	80	47	59@5 15@8	44.5	67	32,212	44	47	22,655
PC	+12	+15	+34	+35	+30	+28.5	+18	81	49	56@4 16@8	43.5	72	34,680	44	49	23,602
C	+10	+14	+36	+40	+25	+28.75	+16	83	59	64@5 12@8	43.25	76	36,607	46	57	28,415
C	+10	+13	+30	+33	+24	+25	+15.33	85	55	52@6 9@8	47	60	28,9[illegible]	46.67	58	27,937
C	+9	+13	+36	+36	+24	+27.25	+15	85	50	55@8	44.75	55	26,492	47	50	24,083
O	+9	+12	+32	+32	+29	26.25	23.33	57	60	36@1 53@8	45.75	87	42,868	38.6	60	28,900
O	+18	+23	+40	+32	+25	30	20.33	84	37	36@3 40@8	42	83	39,978	41.67	37	15,285
PC	+16	+20	+35	+36	+25	+29	20.33	82	42	44@7 22@8	43	66	31,790	41.67	42	20,230
O	+16	+20	+38	+39	+35	33	27.33	89	52	46@8	39	46	22,157	34.67	52	25,047
WO	122	+25	+39	+36	+31	32.75	28.66	84	41	20@3 39@8	39.25	59	27,455	33.34	41	19,748
O	+26	+29	+35	+35	+29	32	28	84	40	45@1 25@8	40	70	33,717	34	40	19,267
O	+26	+29	+40	+40	+31	35	29.33	84	43	53@3 27@8	37	82	39,497	32.67	43	20,712
O	+27	+30	+37	+37	+29	33.25	28.66	84	28	36@12 14@8	38.75	50	24,083	33.34	28	13,486
O	+27	+30	+34	+37	32	32	22.33	83	32	32@11 50@8	40	82	39,497	35.67	32	15,413
O	+17	+20	+32	33	29	26.5	26.66	83	26	42@1 45@8	43.5	87	41,905	35.4	26	12,523
C	+24	27	+35	+33	+28	30.75	23.66	87	43	42@4	41.25	42	20,230	38.14	43	20,712
O	+19	+24														
C					+31		27.33									
O	+24	+27	+34	+35	+31	31.75	30	84	76	36@11 29@1, 33@8	40.25	98	47,203	32	46	22,157
WO	+27	32	+39	+37	+30	34.5	26.33	83	32	34@1 37@9	37.5	71	34,198	35.67	32	15,413
WO	+23	+26	+30	+32	+27	28.75	22.66	86	59	38@2 62@9	43.25	100	48,167	39.34	59	28,415
WO	+22	22	+34	+31	+27	+25.5	21.33	94	44	23@2 +29	43.5	52	25,047	40.67	44	21,193
O	+17	+20	+27	+31	+28	+26.5	22	85	45	47@2 41@8	45.5	87	41,905	40	45	21,675
O	+17	+21	+40	+31	+24	+29	20.33	91	48	+39@2 40@8	43	79	38,052	41.67	48	23,120
O	+17	+20	+40	+32	+24	+29	22.33	56	43	38@2 27@8	43	65	31,308	43.67	43	20,712
C	+14	+20	+41	+32	+23	+29	20.66	85	42	35@1 26@8	43	61	29,382	41.34	42	20,230
C	+18	+21	+40	+30	+23	+28.5	20.66	85	46	37@2 29@8	47.5	66	31,790	41.14	46	22,157
O	+19	+20	+42	+31	+33	31.5	29.66	87	40	39@2 27@8	40.5	66	31,790	32.34	40	19,267

—— 2 start of outside stove

1831 day
1154 Night
2985 lb Burned

0.962 cords by weight
0.8554 cords burned

MARCH

TYPE DAY C: clear O: [illegible] PC: [illegible] W: snow	Outside Air Temperature °F Over night Low	8 AM	12 Noon	4 PM	8 PM	Day (1) time Ave	Night (2) time Ave	Ave pre-heat water temp. °F	Weigh of wood burned in pounds: Time & weight loaded: Prior night's	Daytime consumption	Daytime totals: ΔT +70°F to outside	(3) Lb burned	(4) BTUH @ 100%E	Night time totals: ΔT +62 to outside	(5) Lb burned	(6) BTUH @ 100%E
C	+26	+30	+42	+40	+37	37.25	31.33	35	43	23@1 48@5	34.75	71	34,158	30.67	43	20,712
O	+17	+30	+40	+40	+30	35	25.66	90	139	32@5 33@5	37	65	31,308	36.34	39	18,785
PC	+22	+25	+43	+33	+27	32	24.66	92	39	54@5	40	54	26,010	37.34	39	18,785
C	+23	+21	+41	+32	+25	30.75	23.66	91	47	40@5 24@5	41.25	64	30,827	38.4	47	22,638
PC	+22	+24	+35	+35	+31	31.25	22.6	92	50	60@5	40.75	60	28,900	39.4	50	24,083
C	+17	+20	40	+43	+34	37.25	24.0	83	45	55@5	37.75	55	26,492	38	45	21,675
C	+17	+21	+44	+45	+34	36.0	24.66	88	36	+35	36.0	35	16,858	37.34	36	17,340
C	+15	+22	+45	+48	+39	38.5	30.33	84	45	+41	35.5	41	19,748	31.67	41	21,675
C	+24	+28	+47	+49	+36	39	31.0	84	32	43	33	43	20,712	31.0	32	15,413
O	+27	+30	+46	45	+37	39.5	32.33	85	28	32@4 16@8	32.5	48	23,120	29.69	28	13,487
Cu	+30	+31	+44	43	+37	38.75	32	86	45	54@5	33.25	57	26,016	30	45	21,675
Cu	+28	+30	+42	35	+35	35.5	31.33	86	34	40@5 12@5	36.5	52	25,047	30.67	34	16,377
O	+28	+31	+40	37	32	35	28.66	83	43	50@5	37	50	24,083	33.34	43	20,712
O	+26	+28	+30	33	29	30	26.66	87	39	61@5	42	61	29,382	35.34	39	18,785
O	+24	+27	37	41	35	36	32	86	35	42@5	36	42	20,230	30	35	16,858
O	+25	+32	+45	+48	+35	40	33	85	35	24@8 ~~34@8~~	30	24		29	35	16,858
O	+25	+28	+													
					+30											
O		+31	+36	+40	+40	36.75	+32.66	84	54	43@1 34@8	35.25	77	37,088	29.34	54	26,010
O	+28	+30	+39	+35	+30	33.5	+28	84	38	~~35@~~ 30@8	38.5	30	14,450	34	38	18,303
OCu	+26	+28	+32	+33	+30	30.75	28.33	87	45	36@4 21@8	41.25	57	27,453	33.67	45	21,675
O	+26	+29	+40	+35	30	33.5	28	86	47	25@8	38.5	25	12,042	34	47	22,638
PC	+25	+29	+43	+40	+35	36.75	28.33	87	49	40@8	35.25	40	19,267	33.67	49	23,602
O	+24	+26	+40	+40	+32	34.5	29.33	85	45	45@8	37.5	45	21,675	32.67	45	21,675
PC	+26	+30	+42	+45	+35	38	24	85	39	43@8	34	43	20,712	38	39	18,785
Cu	+17	+20	+47	+44	+34	36.25	25.33	88	35	55@8	35.75	55	24,492	36.67	35	16,858
C	+20	+22	+45	+47	+35	37.25	24	82	23	48@8	37.75	48	23,120	38	23	11,078

APRIL

TYPE DAY C=CLEAR O=O'CAST PC W=WINDY	Outside Temperature °F: OVER NIGHT LOW	8 AM	12 NOON	4 PM	8 PM	DAY TIME AVE	NIGHT TIME AVE	AVE PRE-HEAT WATER TEMP'S	WEIGHT OF WOOD BURNED IN POUNDS: TIME & WEIGH when loaded: PRIOR NIGHT'S CONSUMPTION	DAYTIME CONSUMPTION	DAYTIME TOTALS: ΔT INSIDE TO OUTSIDE	LB BURNED	BTUH @ 100% EFF	NIGHTTIME TOTALS: ΔT IN TO OUT	LB BURNED	BTUH @ 100% EFF
CW	+17	20	+40	+42	33	33.75	24.33	84	30	22 + 35 @8	38.25	77	37,058	37.67	30	14,450
C	19	21	+42	+49	+40	38	27.88	84	35	60 @ 8 [illegible]	34	60	26,900	37.34	35	16,858
PC/W	21	22	+48	+49	+43	40.5	32.33	83	36	40 @8	31.5	40	19,267	28.67	36	17,340
PC	25	+29	55	+55	45	46	38	83	37	48 @8	26	48	23,120	24	37	17,822
O	32	+37	48	48	40	43.25	36.66	84	32	33 @8	28.25	33	15,895	25.34	32	15,413
OW	+34	36	44	43	37	40	31	83	33	46 @8	32	46	22,157	31	33	15,895
OW	26	30	37	41	40	37	34.66	82	62	35 @8	35	35	16,562	25.34	62	29,865
OW	33	37	38	41	34	37.5	26.33	81	52	26 @8	34.5	26	12,523	35.67	52	25,047
PCW	21	24	45	44	39	38	33	82	43	26 @8	34	26	12,523	30	43	20,712
PCW	25	32	49	46	37	40.25	30.33	84	44	50 @8	31.25	50	24,083	31.67	41	19,748
PCW	27	30	42	+40	34	36.5	31	84	50	41 @8	35.5	41	19,748	31	50	24,083
OW	28	31	36	38	32	34.25	30.33	83	48	44 @8	37.67	44	21,193	31.67	48	23,120
CW	28	31	50	49	35	41.25	25	82	42	0	28.05	0	—	37	42	20,230
	19	21														

APPENDIX No. 2

COPIES OF THE MITALAS HEAT LOSS ANALYSIS FOR BELOW GRADE LOSSES, RUN BY MR. MICHAEL CHAPMAN, PROGRAM ENGINEER, ENERGY DIVISION, DNRC.

[illegible] = 8

```
                             * PAGE 1   -  INPUTS *
FILE:  HEATCALC.WRENCH
===========================================================================================
NOTE:  CASE ANALYSIS OF R. WRENCH'S RESIDENCE IN KALISPELL, MT           RUN DATE:
===========================================================================================
+CALCULATION OF OVERALL UA, W/NITE INSUL.       +CALCULATION OF INTERNAL GAINS W/OUT SOLAR
===========================================================================================
SURFACE         AREA  R-VALUE:      SFC UA       *CATEGORY ==>  APPL    LITES   BIO    MISC
                 SF                 BTU/DH                             KW      KW   BTU/HR:BTU/HR:
------------------------------------------      ------------------------------------------
 ROOF 1 =====>  1744     37  ===>    47.1       *SCHEDULE 1:
      2 =====>                ===>      0
                                                 POWER ======>
 WALL 1:=====>  2085   15.7  ===>   132.8        DAYS/WEEK:==>
      2:=====>    95      2  ===>    47.5        HOURS/DAY:==>
                                                       NIGHT:>
 GLASS 1 DY==>   230    1.7  ===>   135.2       ------------------------------------------
       2 DY==>    44    1.7  ===>    25.8       GAIN,DAY=====>
       3 DY==>               ===>      0        ---- NIGHT===>
                                                ------------------------------------------
 GLASS 1 NT==>   230    1.7  ===>   135.2       *SCHEDULE 2:
       2 NT==>    44    1.7  ===>    25.8
       3 NT==>               ===>      0         POWER ======>
                                                 DAYS/WEEK:==>
 DOOR 1 =====>  40.3      2  ===>    20.1        HOURS/DAY:==>
      2 =====>    20      2  ===>     10         HOURS/NIGHT:>
                                                ------------------------------------------
 CRACK 1:====>              :===>      0        GAIN,DAY=====>
       2:====>              :===>      0        ---- NIGHT===>
                                                ------------------------------------------
 GR VOLUME:==>  28247   >*<                      AVERAGE DAY
                        >*<                              NIGHT
 AIR CHGS: ==>    .25   >*<  ===>  105.93       -----------------------------------=======
                                                              * DAY TOTALS:======>
 GROSS FLOOR=>  1716    >*<                                   * NIGHT TOTALS:====>
 SLAB EDGE ==>              :===>      0              (INTERNAL GAINS TAKEN FROM WRENCH'S
                                                      ANALYSIS AND INCLUDED BELOW)
 SOUTH GLASS 1  70.4    >*<
             2          >*<

 T IN  DAY        65    >*<
       NIGHT      55    >*<
-----------------------------------=======
           *** UA DY============>+ 524.43
           *** UA NT============>+ 524.43
               INFIL/TOTAL: ======>+     .2
------------------------------------------
```

```
                         * PAGE 2  -  WEATHER DATA AND CALCS *

==============================================================================================
SITE: KALISPELL   JAN   FEB   MAR   APR   MAY   JUN   JUL   AUG   SEP   OCT   NOV   DEC ANNUAL
==============================================================================================
DAYS/MONTH         31    26    25    13                                              31
  INCLUDE W/O?      1     1     1     1                                               1
  INCLUDE NT ?      1     1     1     1                                               1
EST TAU-ALPHA:     .7    .7    .6    .5                                              .7
AVERAGE TEMP :     22  26.5  31.8    35                                             5.3
  MAX TEMP         29  36.6    42    46                                            14.9
  TEMP SWING        7  10.1  10.2    11                                             9.6
      (TEMPERATURE FIGURES FROM MEASURED DATA FOR THIS TIME PERIOD)
 TFLOAT IN,DY:   26.9  34.1  39.5  43.2                                            12.5   HEATING
          NT:      17  19.8    25  27.7                                             -.9 DEGREE HOURS
      (FLOAT TEMPERATURES BY MONTH WITHOUT SOLAR OR INTERNAL GAINS)                #------------#
 DEG HR DY:     14173  9640  7650  3400                                           19530  54393  DAY
       NT:      14136 10982  9000  4258                                           20794  59170  NITE
                                                                                   #------------#
==============================================================================================
      (BASEMENT COMPONENT HEAT LOSS FROM MITALAS (1982)

BELOW GRADE...   5586  5219  4217  2849                                            5218
ABOVE FLOOR...   2912  3079  2913  2457                                            2456
FLOOR STRIP...   1553  1690  1740  1690                                            1366
FLOOR CENTER..    858   906   954   989                                             823
      (LOSSES SHOWN ARE BTU/HR)
==============================================================================================


==============================================================================================
 * SUMMARY OF LOSS AND GAIN, MY FIGURES, MMBTU
=======================================================================================#======#
SITE: KALISPELL   JAN   FEB   MAR   APR   MAY   JUN   JUL   AUG   SEP   OCT   NOV   DEC WINTER
=======================================================================================#======#


 AUX HEAT DAY    7.43  5.06  4.01  1.78                                           10.24  28.53 MMBTU
 AUX HEAT NITE   7.41  5.76  4.72  2.23                                           10.90  31.03
 BASEMENT        8.12  6.80  5.89  2.49                                            7.34  30.64
   (MY FIGURES)
 SOLAR GAIN:     0.50  0.45  0.55  0.28                                            0.49   2.27
 INTERNAL        3.58  3.01  2.89  1.50                                            3.58  14.57
   (WRENCH'S FIGURES)
---------------------------------------------------------------------------------------#------#


 * NET LOSS     18.88 14.15 11.19  4.72                                           24.42  73.35 MMBTU

=======================================================================================#======#


FUEL POTENTIAL  25.94 19.18 14.45  6.86                                           33.31  99.74 MMBTU
   (WRENCH'S FIGURES)
---------------------------------------------------------------------------------------#------#
=======================================================================================#======#


** OVERALL EFF   72.7  73.7  77.4  68.8                                            73.2   73.5  %


=======================================================================================#======#
                                                                    M. CHAPMAN    8/84
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APPENDIX No. 3

COPIES OF SELECTED RAW DATA TAKEN FOR THE FIREPLACE INSERT MONITORING.

Type of test afterburner, [illegible]

Fireplace Insert Test

Test Date 18 January 1984

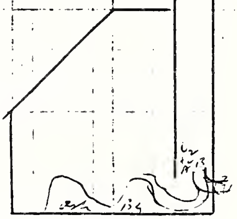
EVENT	TIME	ELAP. TIME hr.	OF CAST IRON DOOR TEMP	INLET AIR TEMP °F	OUTLET AIR TEMP °F	ΔT CONV AIR °F	LB FUEL	RADIANT BTU/H RATE	RADIANT BTUs DELIVERED	CONV. AIR BTU/H RATE	CONV AIR DELIVERED	TOTAL BTUs DELIV
Ent Fuel	9:30	0	—	—	—		8					
Lit fuel	9:40	-	185	65	130	65	17	700		22,884		
Close top	9:45	0.25	225	65	135	70		1150	1662	24,644	23,940	25,60
	10:00	0.5	300	70	157	87		1962		30,629		
	10:30	1.0	445	70	188	118		4500		41,543		
add fuel	11:00	1.5	465	72	161	89		4750	7287	31,333	31,333	35,620
	11:30	2.0	400	72	132	60	12	3610		21,123		
	12:00	2.5	300	72	139	67		1962	2924	23,588	25,583	28,507
	12:30	3.0	385	72	163	91		3200		32,037		
	1:00	3.5	470	73	179	106		4700	4642	37,318	39,430	44,07
	1:30	4.0	510	72	211	139		6625		48,936		
	2:00	4.5	510	72	172	100		6625	5651	35,206	37,436	43,087
	2:30	5.0	480	72	152	80		4900		28,165		
	3:00	5.5	395	72	121	49		3000	3287	17,251	19,715	23,052
	3:30	6.0	300	72	111	39		1962		13,730		
	4:00	6.5	250	72	77	21		1351	1257	8,801	8,801	10,058
	4:30	7.0	152	72	83	11		459		3,873		
	5:00	7.5	95	72	79	7		125	146	2,464	1584	1730
Totals →							37		23,856		187,822	211,678

37 lb fuel burned @ 6426 BTU/lb = 237,762 BTU potential

211,678 ÷ 237,762 = 89.03%

23,856 ÷ 211,678 = 11.27%

Comments: No sign of any combustion in the afterburner chamber.



Overall Efficiency 89.03%

% Radiant heat 11.27 %

Type of test / Test Date: 19 Jan 84

Flue on top, No AB oxy, Basic mode ash bed

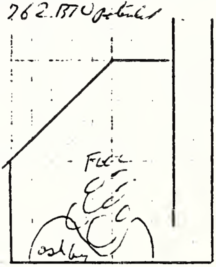
Fireplace Insert Test

EVENT	TIME	ELAP. TIME hr.	°F CAST IRON DOOR TEMP	INLET AIR TEMP °F	OUTLET AIR TEMP °F	ΔT CONV AIR °F	LB FUEL	RADIANT BTU/H RATE	RADIANT BTUs DELIVERED	CONV. AIR BTU/H RATE	CONV AIR DELIVERED	TOTAL BTUs DELIV
8 lb fuel	10:00	0	—	—		—	8	—		—		
load fuel	10:10	-	190	60	125	65	17	800		22,859		
close top	10:15	0.25	220	60	130	70		1,100		24,644	23,946	~~23,456~~
	10:30	0.5	285	65	150	85		1,600	1636	29,925		25,576
	11:00	1.0	450	65	185	120		7680		42,247		
	11:30	1.5	470	67	155	88		4700	4260	30,981	31,685	35,945
add fuel	12:00	2.0	390	68	130	62	12	3400		21,825		
	12:30	2.5	300	65	135	67		1962	2990	23,588	25,935	28,925
	1:00	3.0	400	68	160	92		3610		32,389		
	1:30	3.5	460	70	175	105		4700	4630	36,966	39,545	44,151
	2:00	4.0	490	70	210	140		5500		49,285		
	2:30	4.5	525	72	170	98		6200	5467	34,502	37,084	42,551
	3:00	5.0	460	72	150	78		4700		27,461		
	3:30	5.5	350	72	120	48		2708	2969	16,859	19,481	22,450
	4:00	6.0	265	70	110	40		1500		14,082		
	4:30	6.5	235	70	95	25		1200	1100	8,801	8,801	9,901
	5:00	7.0	160	70	80	10		600		3,521		
	5:30	7.5	90	70	78	8		120	173	2,816	1,584	1,757
Totals →							37		23,198		188,058	211,256

37 lb fuel burned @ 6426 BTU/lb = 237,762 BTU potential

~~Eff~~: 211,256 ÷ 237,762 = 88.85%
23,198 ÷ 211,256 = 10.98%

Comments: Oxygen shut off to afterburner. Test was as close as possible to an exact duplication of 18 Jan 84 test. This was to verify no combustion occurs in the afterburner chamber.



Overall Efficiency 88.85%
% Radiant heat 10.98%

Basic Mode ②

Type of test [illegible]

Test Date 20 January 84

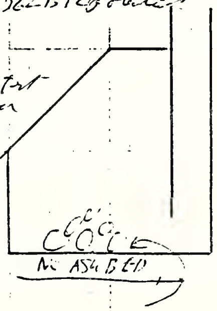
Fireplace Insert Test

EVENT	TIME	ELAP. TIME hr.	°F CAST IRON DOOR TEMP	INLET AIR TEMP °F	OUTLET AIR TEMP °F	ΔT CONV AIR °F	LB FUEL	RADIANT BTU/H RATE	RADIANT BTUs DELIVERED	CONV. AIR BTU/H RATE	CONV AIR DELIVERED	TOTAL BTUs DELIV
Start fire	10:00	0	—	—	—	—	18					
add fuel	10:00		189	65	115	50	17	800	1182	17,603	18,377	19,559
close top	10:15	0.25	218	65	120	55		1050		19,363		
	10:30	0.5	250	67	135	68		1351		23,940		
	11:00	1.0	350	67	155	88		2768		30,981		
	11:30	1.5	325	68	150	82		4300	3239	25,869	27,226	30,465
add fuel	12:00	2.0	350	68	130	62	12	2705		21,828		
	12:30	2.5	300	69	125	56		1962	2080	19,715	22,353	24,443
	1:00	3.0	285	69	150	81		1600		25,517		
	1:30	3.5	255	70	160	90		1600	1721	37,685	31,976	33,697
	2:00	4.0	300	70	180	110		1962		38,726		
	2:30	4.5	300	71	140	69		1962	1841	24,292	28,517	30,358
	3:00	5.0	285	71	135	64		1600		22,532		
	3:30	5.5	220	71	120	49		1600	1066	17,251	16,195	17,261
	4:00	6.0	160	70	95	25		600		8,801		
	4:30	6.5	120	70	80	10		190	303	3521	4644	4947
	5:00	7.0	60	70	75	5		120		1760		
		Totals →					37		11,442		149,338	160,780

37 lb fuel burned @ 6426 BTU/lb = 237,762 BTU's total
160,780 ÷ 237,762 = 67.62%
11,442 ÷ 160,780 = 7.12

Comment: This test is identical to the 19 Jan test except no ash bed. Coals on flat surface

Conclusion! a flow of air around the coals results in carbon, [illegible] lowering efficiency



Overall efficiency 67.62 %
% Radiant heat 7.12 %

Type of test Base Heat Add fuel

Test Date March 4, 1984

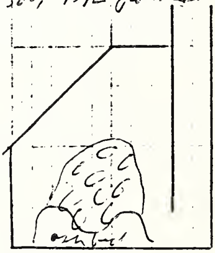
Fireplace Insert Test

EVENT	TIME	ELAP. TIME hr.	OF CAST IRON DOOR TEMP	INLET AIR TEMP °F	OUTLET AIR TEMP °F	ΔT CONV AIR °F	LB FUEL	RADIANT BTU H RATE	RADIANT BTUs DELIVERED	CONV. AIR BTUH RATE	CONV AIR DELIVERED	TOTAL BTUs DELIV
Top fed	8:00	0	—	—	—	—	8					
Start top	8:15	0.25	380	69	180	111	22	3,200	925	39,079	10,679	11,604
add fuel	8:30	0.5	325	69	140	71		2350		24,956		
	9:00	1.0	350	70	140	70		2708	2,703	24,644	25,348	28,051
	9:30	1.5	375	70	145	75		3050		26,464		
	10:00	2.0	475	70	165	95		4050	4347	33,446	32,741	37,088
add fuel	10:30	2.5	500	71	180	109	30	5941		38,377		
	11:00	3.0	585	71	203	132		8800	8613	46,472	46,237	54,850
	11:30	3.5	650	72	225	153		11,095		53,865		
	12:00	4.0	700	74	250	176		13,355	12,603	61,962	61,023	73,626
	12:30	4.5	760	74	265	191		13,355		67,243		
add fuel	1:00	5.0	785	75	288	213	27	17,000	15,785	74,759	73,815	89,600
	1:30	5.5	750	71	300	225		17,000		79,213		
	2:00	6.0	800	73	308	235		18,829	19,363	82,734	83,555	102,918
add fuel	2:30	6.5	850	73	325	252	17	22,261		88,719		
	3:00	7.0	700	73	250	177		13,355	14,539	62,344	65,131	79,670
	3:30	7.5	565	74	200	126		8000		44,359		
	4:00	8.0	415	73	190	117		5,950	4,917	41,191	41,191	46,108
	4:30	8.5	370	72	180	108		2800		38,022		
	5:00	9.0	300	72	165	93		1962	1954	37,741	33,938	35,892
	5:30	9.5	225	72	146	74		1100		26,052		
	6:00	10.0	185	72	124	52		700	800	18,307	18,072	18,872
	6:30	10.5	165	72	100	28		600		9858		
	7:00	11.0	130	71	93	22		200	317	7,775	7511	7828
	7:30	11.5	100	71	85	14		150		4929		
				Totals →			104		86,866		499,241	586,107

104 lb of fuel burned @ 6426 BTU/lb = 668,304 BTU potential

586,107 ÷ 668,304 = 87.7%
86,866 ÷ 586,107 = 14.82%

Comment: This was a maximum fuel load consistent with the insert's ability to physically handle fuel. No signs of any problems. This was a rather awesome amount of heat delivered



Overall Efficiency 87.7 %
% Radiant heat 14.82 %

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